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All communications should be addressed to the Editor.

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Notices of the Royal Aëronautical Society.

Honorary Members.

In response to a request from the Air Ministry, temporary Honorary Membership of the Society has been offered to the following officers representing foreign governments while on service in this country:—

Chevalier W. Coppens (Belgium), Commander Evers (Denmark), Commandant Sablé (France), Major Graziani (Italy), Major-General Itamy (Japan), Captain Kobayashi (Japan), Captain de Vaisseau K. F. Sluys (Netherlands), Captain Scott Hansen (Norway), Lieutenant-Colonel Rich (Spain), Lieutenant-Colonel Mossberg (Sweden), Captain G. Hain (Sweden), Commander Tiselius (Sweden), Major Melvin Hall (U.S.A.), Lieutenant-Commander N. H. White (U.S.A.),

Elections.

The following members were elected in the various grades as shown at a Council Meeting held on April 19th:—

Fellows.—Major T. M. Barlow, A.M.Inst.C.E., C. I. R. Campbell, M.I.N.A.
Associate Fellows.—H. E. Hudson, H. J. Wilkins, A.M.Inst.Aut.E.
Members.—W. M. M. Clark, A. Newman.
Students.—J. D. Campbell, G. Chiverton.
Associate Member.—Flight Lieutenant S. T. Freeman.
Foreign Member.—Commander H. T. Dyer, U.S.N.

Council.

Sir Mackenzie Chalmers, K.C.B., C.S.I., has been co-opted by the Council, in accordance with the provisions of Rule 13, to serve as a Member in the room of Major-General Sir R. M. Ruck, K.B.E., C.B., C.M.G., who vacates his seat (with power to attend) under the provisions of Rule 18 (*d*) on appointment as Vice-President.

Donations.

The Council desire gratefully to acknowledge the receipt of a copy of "The History of the 24th Squadron R.A.F.," by Captain A. E. Illingworth and Major V. A. H. Robeson, from Major Robeson, also a copy of "Telegraphy, Aeronautics and War," by Sir Charles Bright, from the author.

Committees.

At the April Meeting of the Council the following members were nominated to serve on the Committees named. The Chairman and Vice-Chairman are *ex-officio* members of all Committees.

Candidates.—Dr. L. Bairstow, Wing Commander T. R. Cave-Browne-Cave, A. E. L. Chorlton, Captain G. de Havilland, Major H. Grinsted, Professor B. Melvill Jones, W. O. Manning, Major G. H. Norman, N. A. V. Piercy, Dr. A. J. Sutton Pippard, Flight Lieutenant J. E. M. Pritchard, J. L. Pritchard, and Major H. E. Wimperis.

Publications and Library.—Dr. L. Bairstow, Captain W. S. Farren, Captain F. M. Green, Squadron Leader R. M. Hill, Major A. R. Low, J. L. Nayler, Lieutenant-Colonel H. W. S. Outram, Flight Lieutenant J. E. M. Pritchard, A. V. Roe, Major H. E. Wimperis, and the Editor.

Finance.—Lord Cowdray, J. B. Maclean, Sir R. M. Ruck, A. E. Turner (Hon. Treasurer), and F. P. Walsh.

Representatives on other Bodies.

The following members have been appointed to represent the Society on the various bodies with allied interests :—

B.E.S.A. Nomenclature Committee.—Dr. Bairstow, Major Low, Colonel O'Gorman, Dr. Sutton Pippard, Major Southwell, and the Secretary.

Joint Standing Committee with S.B.A.C.—Chairman (*ex-officio*), Vice-Chairman (*ex-officio*), Dr. Bairstow, Wing Commander Cave-Browne-Cave, Lieutenant-Colonel A. Ogilvie, Lieutenant-Colonel M. O'Gorman, and Major-General Sir R. M. Ruck.

Conjoint Board of Scientific Societies.—Colonel O'Gorman.
Aeronautical Research Committee.—Colonel A. Ogilvie.
British Engineering Standards Association.—Colonel O'Gorman.

Library.

The following books have been received and placed in the Library :—" Meteorology," by A. E. M. Geddes, O.B.E., M.A., D.Sc., " The Mechanical Principles of the Aeroplane," by S. Brodetsky, M.A., Ph.D., " The German Air Force in the Great War," Major G. P. Neumann, " A History of Aeronautics," by E. C. Vivian.

W. LOCKWOOD MARSH,
Secretary.

PROCEEDINGS.

EIGHTH MEETING, 56th SESSION.

The Eighth Meeting of the Fifty-sixth Session took place on Thursday, February 3rd, 1921, in the Hall of the Royal Society of Arts, London, Dr. G. C. Simpson presiding.

The CHAIRMAN said he did not think it was necessary for him to introduce Major Dobson, who would read his Paper first. He might say, however, that he was one of the very few men who were engaged on meteorology in relation to aviation before the war commenced. Throughout the war he took part in the experimental work at South Farnborough, and therefore he had had a very long connection with meteorology in aviation which would make his Paper of much more value.

Major G. DOBSON then delivered the following lecture :—

METEOROLOGY IN THE SERVICE OF AVIATION.

It has been supposed that meteorology must necessarily be of very great importance to aeronautics, and that important as it may be to, say, marine work, the services which it can render to aviation are still greater. It may not be without interest, therefore, to discuss in what ways it can be of most assistance; how an ideal meteorological service might be organised, and how far it is likely to satisfy the demands made upon it. We do not propose to discuss what should be done in the immediate future, since this is complicated by so many considerations, such as the financial outlay which is justified by the existing volume of aerial traffic. But to simplify our question, let us imagine a time when the amount of aerial traffic will be so great that the financial considerations involved would justify any outlay that we are likely to propose. Such a time may be supposed to be many or few years ahead, according as one feels, pessimistic or optimistic, regarding the future of commercial aviation. Now one of the most useful results of the lectures given before this society is to afford a basis for discussion afterwards, and if we here put forward one scheme of action, it is hoped that the criticism and alternatives brought forward in the discussion will correct it where wrong and amplify it where needed.

It appears that meteorology should be of service in two main ways: (I.) by providing necessary information regarding all weather conditions which are likely to be encountered on any journey; (II.) by providing statistical information which may be required to settle certain definite questions and by explaining the physical causes of various phenomena.

Part I.—Daily Weather Service.

We may sub-divide this section into four parts, according to the information which is required by an aeroplane starting out on a long journey.

(1) Information regarding the probable wind which the aeroplane will encounter at any height at which it may fly along its route. This will be required both as an aid to navigation (almost essential if the flight be above clouds), and also for selecting the best height at which to fly.

(2) Information regarding the heights of the upper or lower limits of the various cloud layers, so that one may decide whether to fly above or below cloud.

(3) Ample warning must be given of any possibility of the clouds becoming so low as to touch the ground at any point along the route, or the formation of a ground fog.

(4) An indication of the general weather likely to be encountered along the route, with particular warning of any squalls, etc., which may be encountered.

To obtain an estimate of the probable winds, we may adopt one of two courses; either we may place our observing stations along the flying routes and telegraph to a central station (probably by wireless) the actual winds at certain fixed times, at fairly short intervals, or we can attempt to forecast the wind some hours ahead, in which case the observing stations must be located rather differently. The former is much the simpler method, and has the advantage that a few observing stations will suffice at first along the most frequented routes. As aviation progresses, and new routes become used, the observing stations can be extended along these also. Thus, no sudden demand is made on the exchequer, a point of considerable practical, if not scientific, importance! In this case we should make—at any rate at the beginning—little attempt to forecast the wind at a future time, but should trust to its remaining much the same as when the measurements were made. If this method be adopted the observations must be taken at frequent intervals and transmitted to the central station as quickly as possible. There seems to be a great advantage in employing wireless for the transmission of the information, for not only is there a saving of time, but also any large aerodromes can have their own wireless sets and pick up not only the information as sent out by the central station, but also such of the observing stations as are within its range can be picked up direct, without the delay of going through the central station.

The other alternative is to obtain as much information as possible about the wind and pressure distribution at various heights over a large area, and from this information to forecast the wind for any height, over any district, some hours ahead. A few stations scattered along the flying routes would be of no use at all for this purpose, as it would be essential to have a general view of the whole situation, and to find what changes were taking place, not necessarily at the flying routes, but in a large region round them. This method has the advantage, that the pilot is given a value of the wind for the actual time of his flight and not the wind which was observed a few hours previously. Against this must be set the fact that the process of forecasting will not give perfectly accurate results, even if supplied with the fullest information possible. I have attempted to find how large would be the improvement effected by forecasting, by comparing the errors obtained from trial forecasts which I made, with the actual change of wind in the interval of time for which the forecast was made. Unfortunately the improvement which I obtained was not nearly as large as might be expected, and would not justify any great outlay which might be necessary to obtain it. These results were obtained from forecasts of the surface pressure gradient and do not strictly apply to winds at, say, 5,000 feet or 10,000 feet; but at the same time the improvement effected by forecasting is not likely to be much better when we are dealing with the actual winds at a great height. It is true that the surface pressure gradient is almost certainly more irregular than that high up, but on the other hand we have many more observing stations on the surface than we should be likely to have for upper air work. The main disadvantage of this method, which admittedly gives rather more accurate results, is that to work it at all we must have a large number of observing stations from the start. Thus, the large financial outlay, and the difficulty of getting international co-operation—for observations would be required from a much wider region than the British Isles—would probably be prohibitive at first, considering the amount of aerial transport there is likely to be for many years.

We are thus led to conclude that it would be best to adopt the former scheme, at any rate, at first. As the amount of aerial traffic increased the observing

stations would gradually be extended along the various principal routes, and finally the addition of a few extra stations, in special situations, might allow the second scheme to evolve gradually out of the first. In coming to this conclusion we are, of course, looking at the matter from the point of view of a Chancellor of the Exchequer or the average taxpayer, and not from that of the meteorologist, who would gladly welcome any opportunity to obtain full and systematic information about the upper air.

We must now consider how our observing stations should be placed, and how and what observations should be made. The necessary observations seem to be:—

(1) Wind velocity and direction at all heights.
(2) Heights of the upper and lower limits of cloud layers.
(3) The temperature, pressure and humidity are also desirable.

The various possible methods of observation are:—

(*a*) Pilot balloons observed by theodolites from the ground.
(*b*) Anti-aircraft shell bursts.
(*c*) Sound ranging on pilot balloons with detonators.
(*d*) Determination of the wind from pressure gradients obtained from a number of simultaneous aeroplane ascents.
(*e*) Unmanned kite-balloons carrying recording instruments.

Of these (*a*) is ruled out, as it cannot obtain the wind, etc., above clouds; (*b*) is very expensive and can only be used in unfrequented places owing to the danger from falling fragments, it also requires co-operation of an aeroplane to obtain the wind above clouds, which again adds to the expense; (*c*) was used in France during the war, but there is some danger due to the possibility of the detonators not firing in the air and falling to the ground where they may be picked up by children; (*d*) has the disadvantage dealt with above, that a large number of stations taking simultaneous observations are necessarily required. On the whole (*e*) seems to be much the best. Instruments can be sent up on a fairly small unmanned balloon with certainty to 10,000 feet at all times, except in very strong winds. The running expenses should not be great, as with simple mechanical means of handling the balloon on the ground, very few men should be required. Once the balloon is in the air one man can do everything until it is necessary to take the balloon into its shed again. Observations can be made as easily at night as during the day, and could be made punctually to time.

Kite-balloons have already been tried for this purpose, and a few suitable recording instruments are in being. The instrument is fixed to the cable a few hundred feet below the balloon; as this has the triple advantage of allowing it to be easily fixed and detached—while the balloon is in the air—that it is well removed from any disturbance due to the balloon, and that it affords a much steadier fixing than if it is hung by a separate rope from the balloon. One record obtained by such an instrument is of interest since the balloon was above cloud nearly the whole time, and also since, owing to an accident, the cable broke at the winch when the balloon was at 10,000 feet, so that it drifted away to France with over 10,000 feet of cable hanging from it. It was recovered from there a year later and the record developed. The wind records above 10,000 feet were, of course, meaningless, but the temperature and heights were reliable. The height of the upper and lower limits of the cloud layers is obtained from the humidity record, but this part was not fitted in the instrument which made this record.

Instead of raising or lowering an instrument fixed to the balloon, one might have a number of instruments attached to the cable at various heights which should transmit their readings to the ground. While this is possible—schemes have actually been got out—the complication is great, and the objection to

lowering the balloon is very small. Another possible though awkward method would be to send the instrument by and down the cable by a small sail.

Assuming that we are to use a kite-balloon to obtain the observations, we have now to see how we should dispose the stations. Obviously, they must not be exactly on the route, owing to the danger from the balloon cable; they may, however, be placed, say 30 to 50 miles off the route, preferably on alternative sides. To settle how far apart the stations may be, and at what intervals of time the observations should be made, we require to know how the wind varies, both with change of place and change of time. This is some of the statistical information which we hope the kite-balloons will afford, and there is little accurate data at present. The amount of change will, of course, be different in different parts of the world. We have made a rough estimate of both quantities for the British Isles, both from the values of the pressure gradient, as shown on the daily weather charts, and also from pilot balloon results, etc. As one might expect, small changes of velocity and small changes of direction of the wind are the most frequent, and the frequency of a given change in a fixed interval of time becomes less, the greater the magnitude of the change. The results are somewhat different when we consider "vector" changes of velocity,* since a change in either direction *or* velocity will cause a change in the vector. In this we should expect changes of moderate magnitude to be the most frequent, both larger and smaller changes occurring less frequently. The curves which were obtained from the actual changes agreed fairly well with the theoretical results, assuming any change to be due to a number of causes. Further, it was found that as a rough approximation the magnitude of the average, or "probable," change in any interval of time, was roughly proportional to the square root of the time interval. A somewhat similar rule probably holds, for the average or "probable" difference in wind at any given time at two places at varying distances apart. As a very rough rule we may say that near the British Isles the "probable" vector† change of the upper wind in any interval of time is given by

$$V_t = 3.3\sqrt{t} \text{ m.p.h.}$$

where V_t is the vector change in t hours. A similar formula for the vector difference in wind at any time at two places at distance d miles apart would be

$$V_d = 0.5\sqrt{d} \text{ m.p.h.}$$

These formulæ are only suggested as simple very rough approximations to serve our present purpose and do not pretend to any accuracy.

Suppose we have observations made at the kite-balloon stations as frequently as possible, say every two or three hours, we must probably allow an hour for the collection and distribution of the results, so that altogether we may allow about three hours on the average, between the time the observations were made and the aeroplane flying on its journey. This by our formula would give a probable vector error of nearly 6 m.p.h. If we place the observing stations at intervals of say 150 or 200 miles along the route, the aeroplane should always be within about 100 miles of a station, and the "probable" error due to change of wind with change of locality would be about 5 m.p.h. in the worst case, when it was halfway between the stations. In view of the error due to change of wind

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*When dealing with aircraft navigation, we are generally not so much concerned with a change of velocity *or* direction of the wind alone, but with the result of the two together, or what is known as the "vector" change. For example, suppose the wind to be originally west 20 m.p.h. and then change to W.N.W., and to drop by $4\frac{1}{2}$ m.p.h. to $15\frac{1}{2}$ m.p.h., the vector change will be 8 m.p.h. to the S.W.; and an aeroplane flying in any direction for an hour after the change of wind and steering on an assumed wind of 20 m.p.h. W. will, at the end of the hour, find itself 8 miles to the S.W. of where it expected to be.

†Once out of ten occasions the "vector" change may be expected to exceed about 1.8 times the "probable" change, and in once out of 100 occasions about 2.7 times this amount.

with time, it does not seem necessary to place the observing stations at shorter intervals than, say, 150 or 200 miles.*

As regards the maximum height to which the observations should be made, a kite-balloon can fairly easily be sent up to 10,000 feet, but the expenses increase rapidly if greater heights have to be reached. As most commercial flying is likely to take place below this, 10,000 feet for the highest observation will probably be found sufficient.

With an organisation such as that sketched above, the navigator of an aeroplane ought always to know his wind, with a "probable" error of about 7 m.p.h., and the actual error would be less than 12 m.p.h. on nine out of every ten occasions. This accuracy is none too good, but it is, I am afraid, about as good as can be obtained. The scheme can be started on a few short routes without any great expense, and as well as being useful for immediate navigation purposes, could furnish statistical information of great value to aeronautics.

The second requirement, viz., the heights of the cloud layers, can be obtained from the kite-balloon instrument by means of a recording hygrograph. In addition, it has been suggested that the instrument should take photographs at certain heights to show the types of the clouds.

We now come to the third requisite of warning in any cases where it is possible that the clouds may come so low as to touch the ground at any part of the route. Without this it is doubtful whether there will ever be much over-cloud flying, owing to fear of having to land in the cloud. Forecasts of ground fog are also desirable. Little seems to have been attempted up to the present in the way of forecasting low clouds, from which we can judge the chances of success. However, examination of the humidity of the oncoming air, and the vertical temperature gradients, together with experience of the cloud heights under similar conditions in the past, would probably allow fairly reliable warning to be given of the possibility of the clouds coming down to the ground. Mr. G. I. Taylor has already put forward a scheme for giving warning of the formation of ground fogs in the early mornings, but I do not know of any cases where it has been systematically used.

Finally, the forecasting of the ground weather conditions is much the same problem as is tackled every day in the daily weather report. Special squall warnings would probably be useful. Such a service for squall warnings was in operation in Germany before the war. A very large number of small post offices scattered all over the country, were instructed to telegraph to a central office whenever a squall occurred. By plotting the positions and times of the squall on a large map, it was possible to see how it was moving, and send warning to those places towards which it was travelling.

We have now completed our review of what we consider the best daily meteorological service that is possible for the benefit of aviation, but before closing, the reader will probably not rest satisfied with an indication of how ground fogs may be forecasted, but will wish for some reference to the possibility of clearing small areas artificially when aircraft wish to land. The various proposals for doing this seem to have been attracting considerable attention lately.

There is no fundamental theoretical reason why it should not be possible to clear fog artificially over limited areas. Indeed, if the air were only still, the fog droplets would fall to the ground by their own weight at a rate of something like a metre per minute, so that they could clear themselves in a comparatively few minutes. Again, no appreciable energy would be required to make say 1,000 droplets slowly collect together, when they would form a drop big enough to fall

* Where the causes of error are not connected in any way, the error due to many causes together is obtained by finding the square root of the sum of the squares of each error, and not by simple addition.

in spite of the turbulence always present, and which prevents the smaller drops reaching the ground. In actual practice, however, the problem does not seem very hopeful. The air is never still, but has always a slow drift of a few miles per hour, and the direction of this drift is often far from constant. Let us now examine some of the suggested schemes, and let us take as an example that we wish to clear a patch large enough for an aeroplane to land on. If we could maintain it perfectly clear, an area 30 yards wide, and say 300 yards long would suffice, but owing to the variable direction of the drift of the air we ought probably to clear a lane quite 100 yards wide and probably more. Let us suppose that the fog is 300 feet deep (and it is often much more), that the wind is 2 m.p.h. (which is probably a low estimate), and that we are to clear all the air which comes over a line 100 yards long at right angles to the direction of the drift. All these values may easily have to be increased considerably.

(1) Artificial Warming.

One suggestion is to warm the air by burning coal, say by having a number of small portable furnaces, which could be arranged in a row. Now to evaporate all the water which exists as drops and warm the air, say 3° C.—so that the fog would not quickly form again as the air cooled—would require about three tons of coal to be burnt per hour, assuming all the heat used to the greatest advantage. Allowing for inefficiencies, probably at least ten times this amount would be required. Such an amount would not be out of the question, but it would need considerable apparatus. The nuclei produced by the burning coal would tend to form a fog themselves, so that the warming would be to some extent counteracted by their presence, but to what extent it is difficult to say. Were it not for the fact that during a fog the usual temperature gradient is generally reversed and the air gets warmer upwards, the heated air would simply rise and draw in more foggy air behind it. This might actually occur on some occasions, when it would be impossible to clear the fog by warming.

(2) Artificial Drying.

If we were to blow into the air a substance like powdered calcium chloride (which is fairly cheap) the water of the drops near any grain of calcium chloride would evaporate and condense on the grain, which would grow in this way until it fell out by its weight. In this case also we should theoretically need about three tons of calcium chloride per hour, but it might be possible to use it with better efficiency than coal, and of course it could only be used for the few minutes just when required, whereas in the scheme for warming the air the fires would always have to be lit in readiness. Once the air was cleared in this way it would remain clear much longer than if it had been warmed.

(3) Electric Discharge.

If a pointed rod be introduced into a jar containing artificial fog or smoke, and be charged electrically till a brush discharge takes place from the point, the fog is quickly cleared in a remarkable manner. Methods of this type have frequently been suggested, but it seems certain that all the imaginable effects of an electric discharge (which easily account for the clearing in a jar) would be enormously too small to cause any appreciable clearing on a large scale. I have not been able to find any positive results where experiments have been made in the open with this method.

If the fog droplets were electrically charged they could be caught on a conductor carrying an opposite charge, or by spraying the air with larger drops of water also charged. Actually, however, the fog droplets—as one would expect—are uncharged except for the minute charge, either positive or negative, which most small particles possess, amounting to not more than that of a few electrons. Such a charge would be quite useless for any method of clearing fogs.

Another suggested electrical method is to charge all the fog droplets artificially—say positively—and then arrange a negatively charged body to catch the charged droplets. We must remember, however, that a fog droplet having a radius of the order of a hundredth of a millimetre cannot retain its charge if the potential be above about 30 volts, which would correspond to a charge of something like 10^{-4} E.S.U. Effects due to such a charge would be negligible. If charged to a higher potential, the air near the droplet is ionised and the charge leaks away.

We may also point out here, that since in an ordinary fog the droplets of water amount to something like 1/5 c.c. per cubic metre of air, if all the droplets were removed in the case considered above, they would form a stream of some 20 to 30 gallons per minute, *i.e.*, it would require a 3 or 4 inch pipe to carry it. Thus, even if we try to clear such a small area as that taken above we have to deal with a considerable quantity of water.

Part II.—Statistical Information.

As regards the second part of our subject, viz., providing sundry statistical information for the use of aviation, there is comparatively little to say. This problem is very much easier than the first, though, of course, somewhat dull except to those who immediately require the information. We have seen, for example, that we ought to know roughly the " probable " change of wind in any interval of time, and between two places any distance apart, for various parts of the earth's surface; also such information as the change of wind with height. In addition, of course, it is important to know the prevailing winds at any place where the winds are sufficiently regular to make the information valuable. Much of this information, especially that applying to the atmosphere near the ground, is already available, and the remainder can nearly always be obtained if it be considered of sufficient importance to spend the necessary amount of money in obtaining it—as, for example, by equipping the necessary kite-balloon stations.

When dealing with statistical information such as the prevailing winds at any place, one must remember that it is of comparatively little value to find the average or most frequent wind, unless we also know how often the wind departs from this value by any given amount. Thus, if we took the British Isles we should find the prevailing surface wind to be approximately S.W. and I suppose about 15 m.p.h.; this information, however, would be quite useless for aviation, as the chances that any given day has a wind very different from this are very large indeed. As another example we may take the distribution of pressure, temperature and density of the air, with height. This will show us, for example, how we should calibrate an aneroid to obtain the most accurate readings, but we require the standard deviations of these values to calculate how often errors of any magnitude will occur.

As we mentioned above, the obtaining of statistical information is usually chiefly the expenditure of the requisite amount of money, and statistics being proverbially dry, it is not proposed to discuss the subject in detail.

In conclusion I fear the average aviator whose patience has carried him this far, will doubtless feel some disappointment that the meteorologist is not likely to help him more in his daily work. I wish it were otherwise, but the values that are given above are those which are the nearest the truth so far as I can arrive at it. At the same time a meteorological service such as we have imagined would be no small advantage to commercial aviation, and if the best value of the wind which can be given to a pilot starting on a flight has a probable error of 7 m.p.h., it is probably sufficiently good to allow him to navigate by it, say above cloud, without reference to the ground, or on coming down through the cloud to pick up his position relative to the aerodrome without trouble.

DISCUSSION.

The CHAIRMAN said he thought it would be better to take the discussion on Major Dobson's Paper straight away. They had now had an unofficial view of the needs of aviation as regarded meteorology. It would be best now to hear something from the other side. He would ask Colonel Gold to open the discussion because he organised the war meteorological service in France, and is in charge of the meteorological service for aviation in this country. He had practical experience, and would set the discussion going.

Colonel GOLD said the Paper was an effort to stimulate meteorologists to greater precision. On reading the Paper through one got the impression that the author was rather more pessimistic about the usefulness of meteorology to aviation than he (Colonel Gold) thought an all-round survey of the subject entitled one to be. The Lecturer had rather confined himself to the idea of flying over clouds or in cloudy weather, and, in that connection, to the accuracy with which information as to the wind could be obtained by the meteorologists. But even if all Major Dobson said were the limit of the meteorologists' powers in dealing with that particular problem, he (Colonel Gold) did not think it would represent the limits of usefulness of the meteorologists to the aviator. He quoted an example which occurred on November 4, 1918, in France. It was a beautiful evening, but he saw from the weather charts that there was going to be a rapid increase in the wind velocity and deterioration in the weather. A forecast to that effect was issued, and it was evidently of service to the aviator, because the next day they received a telegram in the following terms:—"Warmest thanks from 54th Wing for your invaluable forecast last night." If the aviators had had merely exact information of the weather at the place they were going to they would probably have lost their machines; because at both places the night was cloudless without much wind, and things appeared about as favourable for flying as they could have been. That illustrated the main point—that observations along the route could not, *in themselves,* be adequate. They must be combined with meteorological information of the conditions over the area and forecasts of changes along the route. It was necessary to make some distinction between long and short flights. One of his earliest recollections that convinced him of the importance of meteorology for aviation was the case of a pilot starting from Hendon to fly to Scotland. The conditions appeared favourable, but he struck bad weather, which, to a meteorologist, it was obvious that he would strike, as it was coming in rapidly from the west. He crashed in Yorkshire and was killed. If he had been going on a short flight, say, from London to Lincoln, the conditions would have continued favourable long enough for his flight, but on the long flight the conditions had time to change to such an extent as to make the completion of the flight impossible. For a route such as that from London to Manchester he agreed that the best way to secure efficiency would be to have observations such as Major Dobson suggested by means of kite balloons at different places along the route, *combined with general synoptic information,* so that one knew the existing conditions and the changes likely to take place. It was when such changes were likely to take place and their coming was obvious to the expert meteorologist that accidents occurred. More than half the accidents due to the weather arose, not through conditions being bad at the time, but through their becoming bad and through the forecast side of the subject being neglected. A pilot was not so much concerned with the weather at the time he began his flight as with the weather later in the flight and at the time he had to make his landing, and for that a forecast was essential. Although the actual weather in 80 per cent. of the day time occasions might be a good forecast of the weather two or three hours later, it was not always so. What made aviation difficult were the occasions when the actual weather was not an indication of the weather two or three hours later. The Lecturer suggested that they must have one of

two things, either kite balloons along routes or observations of upper air temperatures and pressures taken at different places over the area. He himself did not regard those as alternatives but each as supplementary to the other. He thought the practical development of the idea of getting observations of temperature and pressure over an area in such a way as to enable charts to be made at the different levels in the atmosphere arose out of the proposal to bomb Berlin. The late Colonel Hopkinson, after discussing the matter with him in France, came to England and began the organisation of a series of stations from which such observations would be available. Such stations were essential if the conditions over such distances as that from England to Berlin were to be forecasted; moreover in everyday work the direction in which real progress was looked for in meteorology was by utilising, from a number of stations, observations of the upper air pressure and temperature; the number of those stations need not be anything like so large as the number of surface stations, because the surface distribution and one's knowledge of its normal relation to the conditions in the upper air permitted of a first approximation to the upper air distribution. Four or five over the British Isles would be adequate, whereas for surface charts at least 20 stations would be required. With a dozen stations over Western Europe all giving observations of pressure and temperature at different heights they would be in a different position from their present one in regard to making real improvement in the deductions which were translated into forecasts. That would be a more fundamental improvement than an improvement obtained by getting observations further to the west, because it would result from a better understanding of the processes involved. He ought to have described the arrangements which were already made for meeting the needs of aviation from the meteorological point of view. Briefly there were two types of information supplied, the general synoptic type and the local type. For the former one had information from 20 stations in the British Isles, 15 or 20 in France, and others in Denmark, Norway and so on, and a weather chart was made from which one could say, sometimes with great accuracy and sometimes with less accuracy, the changes that would take place in the next 24 hours. Those reports were made every six hours, so that one could make progressive deductions correcting or confirming one chart by the next. Supplementing these, especially over the London-Continental routes, there were a number of stations reporting, not so much instrumental observations like barometer and temperature, as observations of more direct importance to aviation—the clouds, the height of the clouds and the visibility and the weather in the ordinary terms. So it would be seen that, as far as surface observations and upper air observations in reasonable weather were concerned, they had got what Major Dobson advocated. What they lacked was the upper air observations in bad weather to be obtained from kite balloons along the route London to Paris. These were difficult to get, and could only be obtained by common action on the part of England and France.

The question of fog was considered a good deal in France during the war, and they used regularly conclusions somewhat as follows:—During the period from April to September: (*a*) if the wind at 9 p.m. was above 8 miles an hour there was little risk of fog or mist; (*b*) if the wind was dead-calm there was considerable risk of fog or mist, whatever the thermometers (dry and wet bulb) might read; (*c*) for winds between those the risk of fog or mist depended on the difference between the dry and wet bulb thermometers. They had a table which, in conjuction with other features on the chart, indicated whether fog or mist would develop during the evening.

Statistics were of real importance in any organisation. One would like to know whether a place chosen for an aerodrome was particularly liable to local mists or whether the cloud was half the year within 200 or 300ft. of the ground (as at Princetown), or whether the rainfall was 30ins. or 90ins. and so on. From past statistics one had information about the rainfall and the wind, but no

precise information about the prevalence of low cloud, the height of low clouds and the visibility in the exact terms in which it was obtained to-day. Statistics were also required, in the location of aerodromes, as to the direction from which gales came. In one part of the world nearly all the gales came from the south-west, in another from the north or north-east. In the early days in France, aerodromes were constructed, he believed, so that the hangars opened towards the north, whereas the direction in which they got fewest gales was east-south-east. Occasionally in that part of France they got sudden and severe gales from the north, so east-south-east would have been a more favourable aspect than north. They had, however, realised what the Lecturer had pointed out, and would take his Paper as something to stimulate them to make greater efforts in securing precision, not merely in their observations, but also in interpreting them and forecasting for short periods.

Major-General Sir W. S. BRANCKER said he had often remarked before that meteorology was the very life-blood of commercial aviation. Flying in really bad weather was the one problem of which he could not quite see the solution. It was of vital importance to have rapid weather reporting of local conditions in front of a machine which was trying to fly somewhere. He agreed with the Lecturer that the rapid reporting of local conditions and its rapid translation to the points of departure and arrival was better than the forecast system. The latter was useful to let one know generally what was going to happen, but it was of the greatest importance, just before any particular service was timed to start, to get instantaneous news of the weather in front at the various stages. He did not think there were many accidents caused by the weather. What he was thinking about was regularity in flying, which was interfered with by bad weather. In commercial aviation one must offer regularity both by day and by night, and air services could be made perfectly regular to-morrow except for that one factor of the weather. The Lecturer suggested that the balloons should be 150 to 200 miles apart. That was rather far in this sort of climate. Taking London to Paris, weather reporting stations would be wanted on each side of the Channel and at each end of the route—four stations for 220 miles. If the balloons were 30 or 40 miles off the route they could give only secondary information. Information was wanted direct from the route. It was found in connection with the Paris service that reports from Beachy Head and North Foreland were not of much use. The Lympne and Boulogne reports were most valuable. He had heard it suggested lately that a government official should be appointed *to commercial aerodromes*, who would not only be responsible that all machines were fit to fly, but would also decide whether the weather was fit for flying. He was absolutely against having government inspectors to see that machines were fit and to judge as to whether the weather was fit for flying. The man to decide that was the man in charge of the service at the aerodrome; when aircraft grew bigger it would be the captain of the ship.

Colonel BEATTY agreed that what a pilot wanted was information as to the actual weather rather than a forecast. For commercial work he wanted to know first, was it possible to land at his destination? Secondly, would there be any change in the weather there during the next two or three hours? After that, and subsidiary to it, what weather conditions was he likely to encounter en route?

Information as to the upper wind was not of much value to pilots at present, as commercial flying was mostly done at a low altitude and the pilot could determine the strength of the wind there from his own observations in any reasonable weather.

Major Dobson had specified various instruments as required for the purposes of observation, but had not mentioned the observer. He would probably agree that it was most important to have at the terminal points a really good observer

upon whom the pilots could thoroughly rely. The man was more important than the instruments.

He entirely agreed with Sir Sefton Brancker in his objection to the proposal that government inspectors should decide whether the weather was fit for flying.

Major H. G. Brackley thought what pilots wanted was an accurate report before they started on a flight. At present a number of pilots had not the fullest confidence in the reports or forecasts they had, and would sooner rely on their own judgment than on a report that the weather was all right at the other end. As regarded over-cloud flying, most pilots would rather keep in sight of the ground. He had done a fair amount of above-cloud flying, but not without a lot of fear as to when he would see ground again, and in a number of cases he did not see it for about two hours. For commercial flying it would be best to keep in sight of the ground as much as possible, though if the country were hilly and the clouds low it would be more difficult to decide whether to keep above the clouds for a time. The pilot could only do it if he had a wireless telephone to tell him the weather was all right farther ahead. Captain Timms had asked him to suggest that after the development of aviation and greater precision in navigation, additional sources of information would be available. Pilots or navigators could send reports on routes by wireless telephone of the heights of clouds and the wind velocity at the height at which they were flying, and the multiplication of those reports would assist meteorologists in compiling statistics as well as other pilots crossing the same area. To make the system complete it would be necessary to make the reporting and recording of observations compulsory. He agreed with that too. They could be of great help to those who followed them on the route.

COMMUNICATED.

73, Melrose Avenue,
Cricklewood, N.W.2.
February 10, 1921.

Dear Sir,—With reference to the Paper on "Meteorology and Aviation" by Major G. Dobson, which was read at a meeting of the Royal Aeronautical Society last Thursday, February 3rd, I was unable at the lecture to make a remark on the subject of meteorology and am therefore putting it on paper.

The Air Ministry recently issued in the form of a "Notice to Airmen," a list of specimen questions on navigation, covering the syllabus of the examination which is to be enforced for all applicants for civil aviation pilots' licences in the future. There are 136 questions given, but not one is on the subject of meteorology!

It has been stated not once but a hundred times that meteorology is of primary importance to aviation, and so the total absence of questions on the subject from the Air Ministry syllabus is greatly to be deplored, but I feel sure that the omission is an oversight.

Meteorology is so bound up with aerial navigation that it is part of it, and the future pilot who will have to cover long distances over the continents of Africa, Asia and Australia, not counting the American Continent, will have to depend more on his own judgment of the weather than on reports received from meteorological stations, because for a long time yet these continents will be very poorly served—compared with Great Britain—by meteorological services.—Yours faithfully,

H. R. Gillman.

NOTE ON MAJOR DOBSON'S PAPER ON METEOROLOGY.

This Paper appears to deal with meteorology for only comparatively short flights of a few hundred miles. It is suggested that meteorologists should turn their attention to longer flights, and it would be of considerable interest to know what they could do with the present means at their disposal in the forecasting of weather for flights say from England to Egypt, thence to India, China and Australia. Of course, such detailed information could not be given as in the case of a short flight. The main points that are required would be the movements of depressions while the flight is taking pace. It would be of very great value to the pilot if he could obtain reliable information by wireless as to the approach of depressions, their probable direction and rate of progress.

Another point which requires investigation is the examination of the upper atmosphere over disturbances causing high surface winds. During R.34's flight to America comparatively fine weather was found above the clouds where there was a very heavy sea and wind on the surface.

With reference to Colonel Gold's remarks on forecasting the weather, it is noted that he smiled almost audibly at the suggestion that people, other than meteorologists, could guess the weather. It should be pointed out that meteorology in its modern meaning is a very young profession and should, therefore, be proportionately modest in its attitude towards other people who are endeavouring to foretell the weather. There is, however, a profession of some considerable age which has dealt with wind and weather for many centuries. It is interesting to note that modern meteorologists are re-discovering facts which were known to the sailor for a long time. For instance in a Paper read before the Society on meteorology by H. D. Grant he mentions that an approaching depression may be foretold by the sight of low-lying cumulus clouds in the distance, and he adds that they are frequently difficult to see owing to the haziness. They are easily detected, however, at sunset as the sun disappears when it is three or four degrees above the horizon. This has led to the old saying :—

> " If the sun sets behind a bank,
> A westerly wind you will not thank."

I have heard of no parallel to the remainder of this couplet, which states :—

> " If the sun sets as clear as a bell,
> An easterly wind as sure as hell."

Another instance of this is seen in Colonel Gold's story of foretelling bad weather on a day that appeared to be fine and clear. The old saying that corresponds to this is : " That the worst gale that ever blew came out of a clear sky." There are many other signs too long to catalogue here. I will only mention the firm belief in the influence of the moon on weather.

These sayings are not wild guesses of ignorant men ; they are the result of centuries of experience and should not be lightly ignored, and I think useful purpose would be served by studying them and seeing if scientific explanation could be found for them.

I have instanced one or two cases in which meteorologists have agreed with them, and it is possible that many others will be found to be true as well. Meteorological forecasts in this country are usually given in a very general form, such as " fog in places." This does not help one much, as you still have to guess where these places are, and I think with such a variable climate as we experience in this country considerable use can be made of the ability of guessing, if this be combined with the science of meteorologists.

WOODIS ROGERS.

The CHAIRMAN congratulated Major Dobson on the assumption with which he commenced his Paper—that there were unlimited funds. It was advisable to start with such an assumption, and see what was the ideal to strive for and use the funds available to the best of one's ability to get as near the ideal as possible. Sir Sefton Brancker hit on the fundamental thing, did one want the conditions at the moment along the line or a forecast? It was all very well to say a pilot would rather judge for himself what the conditions were at the other end, but if he could get information from the meteorologist at the aerodrome that there was a fog at the other end he would like to know about it. If, however, one only wanted to know the conditions along the line one had only to tell the meteorologists that was all that was wanted, and they would make arrangements accordingly. But they could not have the above-cloud conditions in that case. It took too great a "bandabast" (to use an Indian expression) to get the above-cloud wind velocities. They could give pilots the height of the clouds and whether they were increasing or decreasing or getting higher or lower. When it became necessary to tell a navigator how to set his instruments or reach a certain point something must be done in the nature of Major Dobson's suggestions. There were considerable objections to kite balloons. They were very expensive and dangerous. After they had been in service for some time air leaked into the envelope and an explosive mixture was formed. They had to be carefully housed, and all sorts of regulations had to be enforced, and it took a long time to get the balloon up to 10,000ft. and to pull it down, develop a record and get results from it. An aviator might get a certain distance off his route, and he would not feel happy if he knew kite-balloons were about. Major Dobson reported how one of his balloons broke away at the winch and 10,000ft. of wire went trailing through the air to France. Meteorologists could get most of the information they wanted from flights by aeroplanes which would take the temperature when ascending and descending. The temperatures could be reduced to heights, and they would have the crude material for calculations. They could calculate from the temperatures and the synoptic charts of the ground observers what the wind would be at different heights, its velocity and how it changed. These aeroplane observations would be wanted four times a day. He looked forward to the day when pilots themselves would be meteorologists. He was disappointed when he went to Croydon to see the use made of their charts by aviators. He came to the conclusion that if the pilot could get his machine off the ground he would go where he was sent, and therefore he was not so interested as the manager of the aviation company, who he understood did study the charts. He looked forward to the day when the pilot would know the ordinary meaning of the isobaric chart. If a pilot looked at the map and saw there was a small depression at a certain place which would give him bad weather he would remember that better than statistics as regarded conditions along the route. As an official meteorologist he would like pilots to come to his office and discuss their difficulties or say how they would like things. By such co-operation they would reach the end they all desired. He was not sure they had not practically got the unlimited money Major Dobson assumed. Since he had taken over the Meteorological Office he had never had his activities really stopped by want of money, and as long as General Sykes was the Controller-General of Civil Aviation he felt sure he would be sympathetic towards every aspect of their work which was economically good in the broad sense.

Mr. DOBSON, in reply, writes:—Colonel Gold's criticism is very interesting and instructive, though I do not think there is really so much difference between his views and those expressed in the Paper as might at first sight appear. There is no doubt whatever that all the surface information which is available should be used to the fullest extent, to obtain an estimate of probable changes in wind and weather. The suggestion is rather that this should be added to the reports of the existing upper air conditions, etc., along the route. In the brief abstract of the Paper given at the meeting, I am afraid I may have given the impression

that the two alternatives were, either forecasting by surface conditions, or use of direct upper air observations *only*. The alternatives I meant to imply were rather the placing of the available kite balloon stations in positions suitable for drawing synoptic charts for high levels, or for obtaining the actual upper air conditions along flying routes; and the contention was that—at any rate at the start—the latter method would be the better.

As regards statistical information, its importance is emphasised in the Paper, but it was thought that the subject did not lend itself to general discussion. Colonel Beaty has suggested that observations above cloud are not really required, since commercial aircraft always fly below cloud. Is it not, however, the case, that they fly below cloud (1) because they have no information of the wind above, by which to navigate; and (2) because they have no certain information that the cloud will not come down and touch the ground at the destination, or at some point along the route; and further, is not this a very serious handicap to flying, which could be removed by an ideal daily weather service.

Dr. Simpson objects to kite balloons, (1) because of the time required to take and reduce the observations; and (2) because of the danger of the wire, and advocates aeroplane observations of pressure and temperature instead. As regards (1) it takes about thirty minutes to haul the balloon down from 10,000ft., and about ten minutes to develop and reduce the record, so that the earliest observation is only forty minutes old. The taking of pressure and temperature observations by aeroplanes, and their comparison with those taken at other stations, in order to obtain the pressure gradient, and from it the wind, at any height, will certainly take longer than this. (2) The wires of the kite balloons would, of course, be well flagged, but the real safety would be obtained by having them some distance off the routes.

He has not, moreover, overcome the two great difficulties which are inherent in the aeroplane method. As pointed out in the Paper, to obtain pressure gradients at heights from which we can obtain reliable wind estimates, would require a considerable number of simultaneous and well distributed observations. This necessarily involves initial expense. The experience with aircraft is almost unanimous in bringing out the great difficulty of obtaining regular observations in almost all weathers. The experience at Orfordness during the war, when questions of safety hardly came in, and with the keenest of pilots, showed that one could not get anything like regular results. After working amongst aeroplanes for over seven years, I am personally quite convinced that such a method cannot provide the regular and accurate observations made to time which are required.

A still further objection is that, even when sufficient observations are available to allow a pressure map to be made for upper levels, we are still some way from obtaining a reliable estimate of the wind.

Several criticisms have been made on the fact that the scheme only appears useful for short flights. This is quite definitely the case, though I would put the distance at say 500 miles rather than 100 as some speakers suggest. Except for airships, aircraft will certainly have to land about once every 500 miles, and then can get information for the next stage even if they have not got wireless communication all the time. With regard to forecasts of journeys of several thousand miles, it will obviously be impossible to give the wind for the whole journey at the start, and this must be obtained at the beginning of each stage. The general weather conditions would be obtained from surface observations just as at present, and a useful forecast might perhaps be made two or three days in advance.

Lieut.-Col. H. W. S. OUTRAM then delivered his lecture as follows:—

GROUND ENGINEERING.

PART I.

Introduction.

(1) The development of aircraft during the war was such that a new and reliable means of transport had come into existence before the Armistice was signed. It possessed the supreme advantage of greater speed than any other form of public transport, although the commercial possibilities of the new service had still to be proved.

A committee was formed under the chairmanship of Sir Frederick Sykes, and as a result of a series of meetings held during March and April, 1919, framed the first Air Navigation Regulations and the directions issued thereunder, which became a part of the law of the land on April 30th, 1919.

In this paper I propose to deal with the sections of the regulations and directions concerning ground engineers.

Schedule 3, paragraphs 5, 7 and 8 of the "Regulations" read as follows:—

(5) All passenger aircraft must be inspected, overhauled and certified as airworthy by competent persons appointed by the owners or users of them, and licensed for the purpose under this schedule, at such times as the Secretary of State may direct, and such certificate or certificates must be produced to the Secretary of State on demand.

(7) No passenger aircraft carrying passengers shall on any day proceed on any journey unless it has previously been inspected at least once on that day by a competent person licensed for the purpose under this schedule, who shall not be the pilot of the particular machine.

(8) If such competent person is satisfied that the aircraft is fit in every way for the flight or flights proposed, he shall sign in duplicate a certificate to that effect, which certificate shall be countersigned by another person in the employment of the owner, giving the time and date of such certification. For this purpose the counter-signature of the pilot may be accepted."

Section IV. of the "Directions" refers to the "competent person" as a ground engineer, and details the procedure for licensing and the form of certificate they are required to render when carrying out their duties.

(2) Three years ago the title of "ground engineer" was unknown. To-day the term is familiar to very few of the general public, and its exact signification to a still smaller number. It is hoped that this paper may clear away any misunderstanding regarding this new profession; provide fuller information than is at present available for candidates desiring a licence as ground engineers; and that the discussion will assist towards our main object, the maintenance of an ever rising standard of safety in aeronautical travel.

(3) It may be well to consider at this stage why the creation of a new class of official was necessary. Every form of public transport is under some measure of Government control. The railways, although their vehicles operate only on their own property, have to conform to Board of Trade Regulations. Public transport services using the seas, the highways, and the rivers are under a larger measure of control in that not only are the members of the public who travel thereon safeguarded, but also the safety and convenience of other users.

The case of aircraft, while similar in many respects, differs fundamentally in that any other form of public service vehicle on land or sea once built in accordance with prescribed conditions and operated under certain limiting regulations only loses its measure of safety through accident, or by a slow process of

deterioration which can easily be detected by its behaviour and checked by occasional external examination. It is possible by the examination of the design of any aircraft to forecast its behaviour in the air, and comparatively easy by careful and detailed inspection to ensure that it is built in accordance with such design and of the required materials. As a result we can certify that the completed aircraft is airworthy, and guarantee that no undue risk will be taken by its passengers or caused to that section of the community over which it passes in its various flights. At the first landing some small damage may be done to some important part of the structure; during the first flight some part of the controls may wear, or a single but vital nut loosen, and in consequence, the aircraft, although landing safely, without any outward indication of the trouble, may within a few hours of the issue of the certificate of airworthiness have passed into a dangerous condition. In other words, a certificate of airworthiness is valid only until the aircraft takes the air, and its validity must be maintained by repeated examination, to prove that everything is in the same condition as when the certificate was first granted.

The ground engineer has been appointed to carry out these examinations.

PART II.

Examination of Ground Engineers.

(1) A candidate, having applied for a licence as a ground engineer, is requested to attend an examining board composed of Air Ministry inspectors. The result of this examination guides the Controller General of Civil Aviation in his decision as to whether the candidate is qualified for a licence.

It has been suggested that the examination should be in part or wholly written, but the experience gained in the last two years is rather against such a procedure, and in favour of retaining the *viva voce* method. When the various courses in aeronautical engineering that have now been introduced at certain colleges are in operation, their successful completion may possibly be accepted as replacing a part of the present examination.

(2) It cannot be too strongly emphasised that any such examination only guarantees to weed out those who are insufficiently qualified. Alone, it cannot prove that all those that "pass" are fully qualified to discharge their important duties. An examining board, having considered a candidate's past experience, questioned him, and formed their joint opinion on his abilities, can do no more than state that in their opinion he is reasonably likely to be an efficient ground engineer. We have had examples of men who have shown brilliance at such examinations, but have developed in practice some little failure in personality which has prevented them carrying their extensive knowledge into effect. It would appear, therefore, that the only way to determine definitely whether a man is a properly qualified ground engineer is to watch him at his work, and in particular to note the results of such work.

The figures given in Appendix I. show that some preliminary elimination of the unqualified candidate by examination is essential. Since the publication of the Air Navigation Regulations in April, 1919, and up till 1st January, 1921, 664 candidates have been examined; 509 passed and and 155 failed. Of the 509 who passed many had applied for a full licence, but were finally recommended as qualified only for a licence in one category, and even that endorsed to apply to but one or two types, as explained hereunder.

(2) It is seldom that any one man is called upon to cover the whole range of a ground engineer's duties, which would call for knowledge of the construction of aircraft, construction of aero engines, and the operation of both the engine and the aircraft.

It has therefore been arranged to issue licences for a part of these duties, to enable men to carry out that section for which they are suitably qualified.

Ground engineers' licences are divided into four main categories:—

(*a*) Rigging and daily maintenance of aircraft at the aerodrome.
(*b*) Overhaul and construction of aircraft.
(*c*) Top overhaul and daily maintenance of the engine.
(*d*) Overhaul and construction of aero engines.

It was found that many candidates required licences for duties for which they were qualified, but which formed only a part of any one of these categories. For example, several candidates only required a licence to certify the overhaul of one particular type of aero engine of which they had the requisite knowledge and sufficient experience of the construction, though they knew little or nothing about other types. In such cases, therefore, it was arranged to recommend the issue of a still more limited type of licence in one category only, endorsed as being restricted to the particular type of engine or aircraft of which the candidate possessed the requisite knowledge.

(3) The examining board report on each candidate's qualifications, and from these reports one fact is most apparent. The majority of candidates may be divided into two classes. One class has a sound knowledge of aerodrome practice, a fair knowledge of ordinary workshop methods, and a surprising ignorance of the qualities of the materials from which an aircraft or aero engine is built, and even less of the many ways in which such materials may be spoilt by bad treatment and ignorance of their peculiar properties. The other class consists of men whose experience has been limited to a large extent to the construction of aircraft or aero engines, and who have gained the knowledge of materials referred to above, are expert in modern aeronautical workshop practice, but have only a very general or theoretical idea of what happens when the aircraft takes the air. Each of these classes is again sub-divided into the metal-worker and the wood-worker. Generally a candidate with good and sound knowledge of metal work has but an elementary knowledge of wood and non-metallic materials, or his knowledge of the latter predominates. Only a few men have shown equally sound knowledge of both branches of aircraft construction.

It has been found that in the majority of cases a candidate can be placed in one of these classes within the first few minutes. The remainder of his examination is spent in ascertaining whether his experience and knowledge in the other divisions are sufficient to warrant a recommendation.

It has also been found that the examination of a successful candidate seldom lasted more than half an hour, but on the other hand it is often necessary to prolong the examination when candidates have failed to convince the examining board of their ability.

On occasion the employers of candidates who have failed have challenged the decision, stating that the man failed was in their opinion a better man than another of their employees who had passed. In such cases inquiries have usually shown that the man may have been a better workman, but was insufficiently qualified to inspect the work of others.

The ground engineer is in many cases engaged in the first instance as a mechanic, and from his employer's point of view his qualifications as a ground engineer may be subsidiary thereto. Only his qualification as a ground engineer can be considered when deciding whether he is entitled to a licence.

PART III.

The Supervision of Ground Engineers.

(1) As has already been mentioned in Part II., the examination of a ground engineer is only completed when his work has been watched.

This is one reason why he must be supervised, but the greatest need for supervision is that the knowledge that this exists, and is effective, provides that

power behind him necessary to enable him to enforce his decisions. The best ground engineer may be faced with the alternative of issuing a certificate for a doubtful machine or the risk of dismissal and replacement by a less conscientious man. If ever, therefore, an operator suggests that his ground engineer should grant a certificate against his inclination, the latter should be able to reply that he cannot do so, since the supervising inspector would recommend the cancellation of his licence, and any certificate would thus become invalid.

On the other hand, the simplest way for a ground engineer to carry his responsibilities is to insist upon immediate replacement of each and every part so soon as the first sign of wear became apparent. Commercial considerations, however, inevitably tend to postpone that moment, and an opposing force is required, obtained by supervision by a disinterested party.

(2) In order, therefore, to supervise the work of the ground engineer, the power of reinspection provided in paragraph 6 of Schedule 3 of the Regulations and paragraph 8 of Part IV. of the "Directions" is exercised.

It was found at an early date that it was impossible to keep in touch with each individual holder of a ground engineer's licence, since a large proportion of those who successfully obtained such licences did not operate.

It was therefore decided to arrange for periodical reinspection of all aircraft in use, and thereby supervise the work of the active ground engineers. The method adopted is as follows:—

All certified aircraft must fly from licensed aerodromes. The Air Ministry have a complete list of such aerodromes, which is kept up to date. Each is visited in turn, and the aircraft examined, the work done by the ground engineers responsible for the daily certificates for such aircraft being checked and noted. The reports thus obtained on each ground engineer are sub-divided and recorded.

It has been found that this method gives a useful record of nearly every ground engineer who is operating. Should any escape such supervision, the fact becomes apparent when they apply for renewal of their licence, and in such cases particulars of the work done are required, special arrangements being made to judge therefrom as to the man's capabilities. If the evidence of his qualification thus obtained is insufficient he may be called upon (under para. 10 of Section 4 of the "Directions") to submit to re-examination before his licence is renewed.

The first two years supervision has shown that operators may be divided into two classes; those whose chief aim is to run a regular and reliable service; who have a number of machines in operation, and employ an organised staff of ground engineers; and the owner-operator or small syndicate with one or two machines, whose main object is to obtain the biggest return for their outlay by "joy-flying," exhibition flights, and the like, at sea coast resorts or inland holiday centres. It is appreciated that at this stage the latter class of operator is important from the point of view of the public education in flight. A man who has had one or two short flights during his summer holidays is more likely to consider the possibilities of proceeding abroad by air on business than a man who has never been in the air. It is, however, this latter class of operator that requires the more careful supervision, and it is claimed that the small number of accidents which have occurred have proved that adequate and efficient supervision is possible without undue expense to the State or such a degree of State control as to seriously hamper the operator.

(3) It is of course essential that the supervising inspector should possess knowledge, ability and experience that will convince the ground engineer concerned that the inspector knows what he is talking about, and equally the inspector must obtain the confidence of the operator (*i.e.*, the ground engineer's employer).

The following incidents in this work of supervision may be of interest:—

In one case it was found that the aircraft had sustained considerable damage owing to a bad landing. The operating company executed the necessary repairs, but having no ground engineer licensed in aeroplane construction, borrowed one from another firm. It was subsequently discovered that the ground engineer was licensed only for daily maintenance and rigging of aircraft, and had therefore contravened the Regulations by inspecting such repairs and signing up for these in the log book.

During a visit to another aerodrome the operating company's machine was found to be in a very bad condition, despite which the ground engineer had been issuing daily certificates of safety. On the case being taken up the man's licence was cancelled by the Secretary of State.

A case was discovered of an aircraft flying without a daily certificate of safety being issued, although it was known that the operating company employed a ground engineer. It subsequently transpired that he was engaged on other work during the day, his services as a ground engineer being available only for evening flights, whereas the company operated both afternoon and evening.

In another case an operating company had employed a man who represented himself as a licensed ground engineer; it was found that although he had applied for a licence he had never actually been examined, and had therefore assumed a position for which he was not qualified.

PART IV.

The Duties of a Ground Engineer.

(1) A ground engineer is responsible for maintaining the validity of the certificate of airworthiness, and to do so is required to certify each day on which a flight is made that the aircraft is safe in every way for flight.

The experience during the past two years has been that in some cases there has been a tendency to consider such certificates as merely a piece of formality which must be fulfilled. Certificates have been signed without the ground engineer being in possession of the necessary evidence. When an aircraft has been granted an Air Ministry certificate of airworthiness, has been used in a normal manner, and is reported satisfactory by the pilot, there has been a tendency to assume that all is well, and to certify accordingly without making that careful examination of the machine and that detailed inquiry into what has happened to it since the last examination, which is essential.

The latter point is particularly emphasised. If the ground engineer constantly travelled in the machine he would know exactly what had happened to it and exactly where to look for possible signs of trouble. He could put his finger on defects which many hours of search would not reveal unless their existence was suspected.

Sometimes the ground engineer hands over the machine to the pilot and takes but little, if any, interest in what happens on its journey, although the pilot generally bases his certificate as to fitness for each flight on the ground engineer's daily certificate, and may also rely on the ground engineer to see that the petrol, oil and water in the tanks are sufficient for the proposed journey. The ground engineer is responsible for the airworthiness of the machine until the very moment when it takes the air, and the last few minutes on the ground and the first few in the air often provide evidence which should be carefully noted.

(2) Aircraft, like any other form of transport vehicle, require continuous maintenance, and the ground engineer is responsible that the machine to which the original certificate of airworthiness was granted is unaltered by such

maintenance. He must also consider the conditions under which the machine is stored; how these are likely to affect the various parts of which the machine is composed; he must be familiar with the deteriorating effects of different storage conditions on the various units of the machine, and if he knows that these are particularly deleterious to one especial part, must watch that part and detect the first signs of deterioration that call for its replacement.

The ground engineer must decide when it is necessary to fit a spare part, whether this be a nut or a complete component. The mere fitting of the new part is but the smallest part of this duty. He must satisfy himself that the part has been correctly made in accordance with the drawings on which the certificate of airworthiness was granted, and is of the material specified in these drawings. It must have been inspected during construction (as laid down in detail in paragraph 21 of Section 3 of the "Directions"), and he must have actual evidence that it has passed such inspection, and further, must satisfy himself that the part has not been damaged or deteriorated since such inspection was carried out. A ground engineer might possibly be excused if he failed to discover a hidden defect that had developed in a machine during flight, but there should be no possible excuse for permitting a new part to be fitted into a machine unless fully satisfied as to its history.

(3) The certificate concerning the fitness of the engines is probably one of the most difficult duties of a ground engineer. Obviously the airworthiness of the aircraft depends very largely upon the engines. No one would dream of certifying that a machine designed to use engines developing 300 h.p. each was airworthy if fitted with engines developing, say, 200 h.p. each, yet some have tried to use aircraft when the engines have lost power to such an extent that it has been almost impossible for the machine to take off with its full load.

Records taken over a considerable period show that for every eight forced landings due to engine failure, one is actually due to defect in the engine itself, the remainder being directly caused by some default in the installation of the engine. So long as the engine and the aircraft structure are designed as separate units, installation must remain a weak point of the whole machine, so that the ground engineer must give his constant attention to the daily routine of cleaning petrol filters, checking petrol flows and water connections, etc., ensuring that all ignition leads, switches and contacts are in good order. He should verify each day that the engine runs up to its proper speed, see that the oil pressure builds up and is properly maintained, and that the radiator temperature is normal. He should also make a point of inquiring of the pilot as to any sign of excessive engine vibration in the air, the flexibility of the engine and any unusual circumstances which may have characterised its running during the daily trips. His discretion must be used as to the period of running requiring a top overhaul for cleaning purposes, minor adjustments and replacements, and in due time have the engine removed for complete overhaul. No hard and fast rule can be laid down as to the period of running before top overhauls and complete overhauls should be carried out, since there is still a considerable variation in this respect, even in engines of the same design and origin.

The repairing of an engine requires on the part of the ground engineer in charge of it almost a wider and more detailed knowledge than is needed in the building-up of a new engine, in that he must determine the safe limits to which crankshafts, cylinders and the like may be reground, and the extent to which part-worn components may be retained. A sound knowledge of materials and their heat treatment, too, is essential to justify his responsibility in the acceptance of new parts. This all-round knowledge is not easily obtainable under normal conditions of works organisation and employment. More often than not a would-be ground engineer is found to have excellent experience in the erection and testing of a particular type of engine, but for materials and heat treatment he has relied entirely, and probably quite justifiably, on another department of his

works organisation. So long as he has this other department to fall back on in his supervision of the overhaul of the engine, he is safe, but it is eminently desirable that he should endeavour to improve his own knowledge, and so become self-supporting and capable of carrying through his job on his own, and without the resources of a complete works organisation, which may not always be at his disposal.

(4) One result of both Service and civil experience is that various small points come into prominence which it is desirable to draw to the notice of all ground engineers. "Notices to Ground Engineers" are therefore issued. A list of these publications to date is attached as Appendix II. They are published in the technical press and are sent to all registered owners of aircraft, who are expected to pass them on to their ground engineers. To make certain that they are obtaining these "Notices," ground engineers are required to state that they are in possession of a complete and up-to-date set when applying for a renewal of their licences.

It is here urged that ground engineers and aircraft operators generally should suggest matter for such Notices. Experience with any particular type of aircraft or engine usually brings to light the little troubles to which it is particularly prone. Such experience gained by the larger Companies operating a number of machines would be of value to the owner or operator of a single machine of the same type, and in many cases to owners of machines of similar types, and could often be published as "Notices to Ground Engineers" with advantage.

Occasionally particular points of weakness only become apparent after more or less prolonged use or as the result of an accident. When such cases come to light the certificates of airworthiness for all machines of the type in question are suspended until such time as the defect has been remedied. Information of such suspensions is issued as a "Notice to Ground Engineers." Once the ground engineer's attention has been drawn to a point of weakness it is sometimes possible to permit the aircraft to fly until temporary or permanent replacement has been made without taking the machine out of service.

It is an important duty of the ground engineer to pay particular attention to the terms under which certificates are thus modified, and he must adhere strictly thereto while continuing to grant the daily certificate.

(5) The insurance of aircraft is already of such importance as to call for a separate paper, and on this occasion it is only proposed to touch on one aspect, that of the relation of the ground engineer to the insuring company. So far as the Air Navigation Regulations are concerned, the ground engineer is only required to certify that the aircraft is in every way safe for flight. The risk of insuring any aircraft is governed to a large extent by the following points, all of which have to be taken into consideration:—

(*a*) The design and primary standard of construction of the aircraft.
(*b*) The condition of the aircraft when setting out for the flight.
(*c*) The nature of the flight and the proposed load.
(*d*) The skill and experience of the pilot, particularly with regard to the particular journey undertaken.
(*e*) The meteorological conditions at the time of the journey.

Of these factors the second is that which concerns the ground engineer. It may often, therefore, be his duty not only to maintain that minimum standard insisted upon by his supervisors, but a higher standard which may be laid down by his employers, by the reputation for which they may obtain advantageous insurance terms.

(6) It is suggested that it may be found necessary to consider the formation of a superior grade of ground engineer. It is already probable that a large operating company would find it desirable to place their ground engineers under the control of one man who had higher technical qualifications and ability than are

required for the ordinary ground engineer. Such a man would go far towards ensuring the reliability of any service and would advance the status of "ground engineering" nearer to that which must be attained if these men are to safeguard adequately the aerial transport of the future.

I must apologise for the fact that this paper is so disconnected and inconclusive, my excuse being the fact that ground engineering itself is still in an experimental stage and awaiting its certificate of approval, and in conclusion must state that the foregoing notes and remarks represent nothing but my own interpretation of the regulations and my personal views on the subjects dealt with. They have not been in any way authorised by the Air Ministry, and must not be assumed to be in any sense official statements.

APPENDIX I.

RESULT OF EXAMINATION OF GROUND ENGINEERS.

Categories.	No. Passed.	No. Failed.	Total Applications.
A	139	17	156
B	2	2	4
C	130	31	161
D	12	2	14
A B C D	8	15	23
A B	76	33	109
A C	36	9	45
C D	81	40	121
A C D	18	2	20
A B C	7	4	4
B C D	—	—	—
B C	—	—	—
Totals	509	155	664

Total number of ground engineers licensed to 31/12/20 ... 509
Per cent. operating during 1920 *and under supervision* ... 26%

APPENDIX II.

AIR MINISTRY NOTICES TO GROUND ENGINEERS.

No. 1.—Explanatory Statement.
No. 2.—Petrol-Resisting Rubber Tubing and Connections.
No. 3.—Streamline Wires.
No. 4.—Safety Belts and Harness.
No. 5.—Control Pulleys and Running Cables.
No. 6.—Arrangement of Oil Filter on Aeroplanes fitted with Napier "Lion" Engine.
No. 7.—Avro 504 and 536 type machines: Upper Shoe Fitting for Engine Diagonal Strut (Part 100).
No. 8.—Fitting of Ballast in Aircraft.
No. 9.—Defects in Aircraft Timber.
No. 10.—Foreign Matter in Petrol Systems.
No. 11.—Strength of Control Cables.
No. 12.—Avro 504 and 536 type machines: Upper Shoe Fitting for Engine Diagonal Strut (Part 100).
No. 13.—Handley Page 0/400 Tail Plane Fittings.

No. 14.—Beardmore Engines, 120 h.p. and 160 h.p.
Water Pipe, Part No. 11358/12 B, Connecting the Top Water Rail with the Carburettor Jacket.
No. 15.—Siddeley "Puma" Engines: Disuse of High Compression Pistons.
No. 16.—Renewals of Licences: Complete Sets of Notices Necessary.
No. 17.—Air Navigation Directions Amendments: Authorised Patterns of Log Books to be used.

DISCUSSION.

The CHAIRMAN said it was a pleasure to the layman to read Colonel Outram's paper, which, though technical, was written in untechnical language. It dealt with another form of Government control. They had got so used to Government control that one almost forgot that before the war they had practically none of it. As long as it was directed to something which was thoroughly understood he did not think anyone objected to it, provided it was effective. If it was not one was restive under it. As an example of inefficient Government control he mentioned that some years before the war, when there was plague in India, a system of plague inspection was instituted at Port Said. All the first class passengers were fetched out of bed at six o'clock in the morning, filed in front of a doctor and went back to their beds. It annoyed them very much, as any of them might have been bad with the plague and the doctor would not have noticed it as he did not know their usual appearance. That made them restive and it would be the same with this ground work unless the pilots knew that the inspection was done well and that their safety was insured by it. An inspector who ordered the alteration of controls might be making himself a nuisance, but the pilots would come to respect him, as they would see he was not there just for the fun of the thing. Colonel Outram would be glad to have constructive criticism, and he thought any criticism was likely to be constructive, as the whole thing was so new.

Captain P. D. ACLAND congratulated Colonel Outram on the able manner in which he had dealt with a very difficult subject and on the clear way in which he explained the steps being taken to put in motion the new duties called for under post-war civil aviation.

He stated that he had discussed the whole of this question with his own pilots and engineers at his works, and they all agreed that the work to be undertaken in this new profession was of prime importance. If machines were going to be kept in good order regularity of service is very materially assisted, for after all, if machines cannot fly safely the rest of the organisation would go for naught. In this connection he felt that the actual constructors were bound up with the transport companies at the present time owing to the fact that in the present stage of development the closest liaison between designers and operators was essential if useful types of commercial aircraft are to be evolved.

The question of the certification of ground engineers is one which gives rise to several problems. It is suggested that under existing conditions it is a simple matter for a man to receive a ground engineer's certificate who had had none of the practical experience of aircraft which is considered essential. It is felt that a high standard of knowledge of the art of aviation—that is flying—is more important, perhaps, than that of engineers on a ship. Up to the present, to attain practical training and experience presents difficulties, for men who have been through the shops are possibly inclined to be pedantic with shop practice, and those with only outdoor experience are not sufficiently familiar with the best methods as applied in the shops. It would appear that if many of the fine mechanics who graduated in the Flying Corps had an opportunity of further training in workshops and vice versa, there would be a blend of knowledge which might be useful for future working. The education of future ground engineers

is now receiving consideration and opportunity is being given in universities and elsewhere for furthering this knowledge; in particular, it is reasonable to expect that in time many valuable ground engineers will be drawn from the young men now being trained in the well-equipped establishments being set up for the Royal Air Force.

The inspection of ground engineers and their work is a question which is closely bound up with insurance. It is well known that the airworthy certificate was a minimum, whereas certification should be classified as is done in all forms of insurance.

It has been pointed out that a Government department should not be the only supervisors of ground engineers as they are unable to give a classification and not in a position to state, without some legal ceremony, that one concern is better than another—they can only hold to the letter of the law and classify machines as fit to fly. Efforts have been made and conferences held with the aeronautical inspection directorate to see if a way could be found to alter this, but it had been found to be impossible.

It is felt that possibly a beginning could be made by the creation of a civil organisation which in due course would be run on the same lines as is done in the case of shipping. In this connection a start had been made with an aircraft register and a pilots' register at Lloyds. The point was, had not the day come when a modest beginning might be made by the appointment of, say, one or two inspectors at terminal aerodromes, independent in their duties and responsible to Lloyds, to whom their reports would be presented? From these reports it would be possible for the various risks as represented by machines operated by operating companies, and also the efficiency of their staff and the skill of their pilots to be classified.

He drew attention to the cases mentioned by Colonel Outram where ground engineers' work had been found to be faulty. He would like to have seen also the further remarks as to the action taken in these cases, for there is no doubt that faulty or careless work on the part of ground engineers may very reasonably lead to accidents which did considerable harm to the cause of civil aviation.

Brigadier-General R. K. Bagnall Wild said that the subject of the ground engineer had not been sufficiently ventilated. Technical details might form a useful appendix for Colonel Outram's paper. He thought many of the operating owners of machines scarcely realised the extent and responsible nature of their ground engineer's work, and he was sure a number of pilots were hardly aware of the amount of care and attention the ground engineer gave to a machine. The larger operating companies should shortly have a super-ground engineer of higher capabilities, such as aerodrome manager, to look after the rank and file. It has been stated that the ground engineer was an expensive luxury, but where the ground engineers' work has been good the money spent on them has been saved more than ten times in cost of repairs and fuel per passenger-mile alone, apart from the safety of the public. In his opinion Lloyds should, at an early date, start with one or two inspectors and consider the claim of any operating firm for a rebate off insurance premiums. Many firms ought to get insurance terms at half and sometimes a quarter the present rates, but cannot expect this unless their ground engineers' work is sound and their advice acted on.

The Air Ministry require a minimum of safety, but it is not only that minimum of safety which is being obtained at the present moment; the ground engineers by their efficient work have undoubtedly, in many cases, enabled the machines to be maintained in a greater degree of flying excellence than the minimum required. The operating firms have to look after their machines from hour to hour and minute to minute, especially is this so—as pointed out by Colonel Outram—during the few minutes before flight. No Government can guarantee the execution of such work. It is up to the ground engineer to do his work and up to the operating

firm to employ none but the best, and—a most important obligation—the operating firm must back up the ground engineer in every possible way.

Captain GOODMAN CROUCH remarked that Colonel Outram had dealt more with the ground engineer than with ground engineering. It was not, by any means, an easy job, and, although one could bind the ground engineers by regulations, a great deal remained with them as to adapting an intelligent and keen way of going to work, especially as they were torn between two interests, holding their certificate from the Government and being paid by the firm. As a contrast to that he might mention that during the war he passed out over 500 machines, but there was no difficulty, as everyone was keen to help him. The ground engineer might find it difficult to enforce his opinion. Records obtained by ground engineers should be kept for reference. Ground engineers would like to have the information picked up at other stations. It might be useful to get to know the ordinary life between overhaul periods. It was discovered during the war that certain small types of machine lasted 40 to 45 hours' flying without requiring overhaul, larger ones 60 hours, and still larger ones 90 or 100 hours. That information might be of considerable value to the ground engineer. They were all anxious to get rid of Government control, but in this case it concerned the safety of the public. How could machines be classified into groups for different insurance premiums? Accidents due to structural weakness were negligible.

Lieut.-Colonel BEATTY said that the Government must control all forms of public transport sufficiently to ensure the safety of the public.

The lesson learnt from the early days of railways caused such control to be adopted at the inception of civil air transport. The maintenance of the aircraft is probably the most important point to control in air traffic as far as safety is concerned, and Colonel Outram had given a clear description of the system of Government control, which consists in legal compulsion on the owner to employ responsible men of a certain standard of skill and knowledge, whose work is supervised by Government inspectors. Captain Crouch has pointed out the weak point in this system, which is using an employee of the owner as the responsible person.

The only practicable alternative scheme would be to have Government inspectors for each machine, and such a system would undoubtedly tend to kill air transport by overmuch bureaucratic control.

Captain Acland has referred to the desirability of taking drastic action against ground engineers who do bad work.

The Secretary of State has wide powers under the Air Navigation Act, but he would be a rash man who inflicted punishment for infringement of any regulations without *legal* proof of such infringement. No Government department could possibly act in such a manner in England, and the difficulty of obtaining legal proof may frequently enable offenders to escape.

The active co-operation of the industry, and more especially that side of it which is concerned with insurance, will do much to strengthen the present system and to remove any cause for complaint.

Insurance provides a means of rewarding good work by reduced premiums, while punishing bad work by increased premiums or refusal to insure.

He hoped as air traffic develops we should see introduced a system of rebates on premiums where the maintenance work is really good—the ground engineer concerned receiving a share of such rebates.

Such a scheme should result in first rate maintenance with a minimum of Government supervision.

It is possible also that the industry might benefit if owners employed ground engineers recommended by the constructors of the aircraft, and he should certainly

like to see the aerodrome managers of a transport firm holding licences as ground engineers and taking responsibility in questions of maintenance in special cases.

Mr. L. Woods Humphery (communicated):

1. I am sure that everybody in the aircraft industry appreciates the very efficient way in which the examination of ground engineers has been carried out in the past, and it is the earnest hope of all operators that the Examining Board will keep up this present standard and will gradually incline more and more towards the Board of Trade policy in respect of marine engineer certificates until it practically coincides therewith.

2. In part two, can you explain further why those applicants who applied for full licences were only finally recommended as qualified for a licence in only one category, as in many cases it is extremely desirable that a man should have a full licence, as it may save a company sending two or perhaps three men abroad for perhaps a long and expensive journey instead of only one man?

3. Your observations on the difficulties encountered by the Examination Board are only too well appreciated. The ground engineer's position is not a little an anxious one, even from the employer's point of view, as it is almost invariably necessary to use ground engineers as foremen, though one is not necessarily the other. The employer neither wants to run the risk of a crash, which may ruin his business, nor does he want to run the risk of large maintenance bills, which may equally ruin his business.

4. No mention is apparently made of the question of suspension of licence. One would not like to think that a man, having had his licence cancelled, is deprived of all chances of re-employment in his profession.

5. Last, but most important, is one perhaps not definitely applicable to the discussion of ground engineers, but nevertheless it affects them very considerably. The question of basing the depreciation, wear and condition of any aeroplane, engine or parts on the basis of the "hours" they have done in the air. Nothing could be more ruinous practically, in view of the very little experience which anybody has yet in regard to the real life of any of these things.

The Appendix 2 of your paper happens to draw my attention to the one concerning the disuse of the high compression Puma engine; it reminds one also of the Rolls-Royce. I have many figures on this subject, all of which would show without question that the high compression engine of both of these types saves from 20 to 40 per cent. in overhaul costs over the low compression. It cannot be too strongly emphasised that the very greatest care should be taken and the utmost possible evidence obtained before any notices such as the withdrawal of the engine of an aeroplane or part thereof from the approved list are issued. I think I am right in saying that too much evidence is taken at the present from R.A.F. service experience, or from the makers; with regard to the R.A.F. experience, the conditions are, I think, sufficiently different from the commercial as to be almost incomparable. They use higher altitudes, they stunt, and they invariably run their engines on a higher percentage of their full power. Concerning the makers, I do not think it follows necessarily that they know more about their own engines than anyone else, and I am sure it will be agreed that it will be iniquitous to have a system which makes it possible for engine manufacturers, by reason of recommendation to the Air Ministry, to be in a position to enforce the operating companies to entail expenses which may amount to thousands of pounds, without the very fullest investigation from all possible points of view, and the maximum evidence being obtained and published.

General Sir Sefton Brancker said that at first sight the position of a ground engineer under present regulations is an anomalous one, for he is responsible to his own employer and to the Government, and it is conceivable that the interests of each of these authorities might clash. The

only other alternative appears to be to appoint a ground engineer to each commercial aerodrome, who will be the servant either of the Government or of Lloyds. This has several serious disadvantages. When traffic was slack this official would have very little to do; when it was brisk his presence would probably cause delays because he would not be able to clear the aircraft of several companies at the same time. His inspection of the aircraft must inevitably be more perfunctory than that of a man who is not only responsible for the fitness of the aircraft to fly, but is also probably in charge of its actual maintenance. Further, a cautious official, in order to avoid responsibility when in any doubt, would refuse permission to fly, whereas a ground engineer whose interests lay with the welfare of his own company, as well as with Government regulations, would be more broad-minded.

He was of opinion that the present system is probably the best possible under the circumstances. An efficient company which is running a service in the best interests of the public would be only too glad to accept the supervision of a really good ground engineer whom they know and trust. It is probable that any clashing that may occur between the allegiance to the Government and the allegiance to the employer will be the result of inefficiency on the part of the company.

He would like to emphasise one point that the lecturer makes—that out of every eight forced landings, due to engine failure, seven are the direct result of faulty installation. It is in perfecting our installation that we must concentrate our efforts for the moment in order to make aerial services more reliable. He always contended that we have brought the engine and the aeroplane to such a pitch of perfection that with proper supervision engine failure need never occur, but installation still leaves much to be desired.

Mr. Woodis Rogers: I must confess to being disappointed with this paper because, not having read an advance copy of it, I was misled by the title into supposing that it referred to engineers.

I think the whole principle upon which this system is based is wrong, as it puts the onus of inspection on the Government rather than on the individual who owns the machines. It necessitates a large number of inspectors who deteriorate in quality as they increase in numbers, and they appear to be mechanics of the "sticky tape" variety. This gives far too much power to uneducated men and must create a very heavy burden for civilian flying to carry in the way of unnecessary obstructions.

It should be quite unnecessary for a Government official to inspect a machine before every flight. This duty should be carried out by the owner of the machine, who should have an engineer responsible for this work in his own employ, who would work in close conjunction with the pilot in rectifying any fault which they notice.

This would reduce the number of Government inspetcors very considerably and they could be men of high qualifications of similar standing to Board of Trade marine inspectors. These inspectors would periodically visit aerodromes and inspect machines. If any case was found where the machines had not been maintained in the condition in which they were when they were passed originally, the owner of the machine should get into very serious trouble, such as something to do with "boiling oil."

This would put the matter of inspection on similar lines to the Board of Trade in relation to ships, where the onus of maintaining ships between periodical inspections rests with the owner.

It is obvious that it is to the interest of the aircraft owner, even more than in the case of a ship owner, to maintain his machine in a safe condition, as any accidents must be very prejudicial to his business.

COLONEL OUTRAM'S REPLY TO THE DISCUSSION.

The discussion has proved my contention that misunderstanding exists as to the duties and responsibilities of the ground engineer, and has brought forward a number of interesting points.

Captain P. D. Acland, while agreeing that it is essential to maintain a high standard when examining for licences, at the same time recognises the present lack of men with all round knowledge and ability.

The "endorsed" and "limited" licence has been introduced to meet these temporary conditions. It is hoped that in the future an "unlimited" licence will be the rule rather than the exception.

His question as to the action taken when a ground engineer is found to be doing indifferent work had been dealt with by Colonel Beatty.

General Sir Sefton Brancker's opinion that it is probable that a clash between a ground engineer's allegiance to the Government and his allegiance to his employer (which some people seem to think inevitable and an inherent defect of the present system) will occur only in the case of the inefficient company, is most encouraging. It has always been my personal belief.

Major Humphries touches on the "limited" licence question. I would emphasise that a licence is only "limited" when a man's experience is so limited as to be insufficient to qualify him for a full licence. He points out that no mention has been made of the suspension of a ground engineer's licence. Should supervision reveal that a ground engineer is unqualified, the licence must be cancelled, since obviously an unqualified man cannot be licensed until he has obtained such additional experience and education as will make good his deficiencies. On the other hand, faults or failures other than those due to ignorance or incompetence might well be dealt with by suspension.

Mr. Woodis Rogers' notes are typical of the misunderstanding that exists. He states that he considers that the whole principle upon which the system is based is wrong, and then proceeds emphatically to urge a procedure identical with that at present in use.

In conclusion, I would urge that some means of collection, collation and interchange of information between ground engineers is most desirable, and in fact an urgent necessity.

I would like to suggest that this is a function which might well be undertaken by the Royal Aeronautical Society.

Votes of thanks were accorded to the Lecturers, on the motion of the Chairman, and to the Chairman on the motion of Colonel the Master of Sempill.

THE TECHNIQUE OF FLIGHT.

Lectures delivered to the Scottish Universities in November, 1920,

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Flying is an art. A pilot may actually fly a small manœuvrable aeroplane of the present day without knowing much about aerodynamics, just as a musician may draw exquisite music from an instrument without a knowledge of the laws of sound. There is a flying instinct just as there is a musical instinct; an unerring perception of the modes and measures of the art; a subconscious obedience to laws which are at most but dimly realised. I do not say that a pilot can *design* a successful aeroplane without a certain knowledge of the fundamental truths of aerodynamics, of the distribution of stresses in a structure, any more than a musician can compose a sonata without a knowledge of the laws of sound, the laws of harmony and counterpoint, the practice of great masters in the traditions of sonata writing; but I do maintain that he can *fly* the aeroplane. I further maintain that flying demands men of a certain temperament, that in general the temperament of a successful pilot veers rather towards the artistic than the scientific, and that these two temperaments are in most ways opposed to each other. I think it is an undisputed fact that men of scientific temperament seldom make good pilots, and that is the pity of it; for if they did make good pilots the advancement in design of the heavier-than-air machine would be far more rapid than it is.

In these two lectures I am only going to deal with craft which are heavier than air. Hitherto the evolution of their design has to a large extent been based on the accumulated observations of flying men; the "hit and miss" method if you like it. The pilot looks at the behaviour of his aeroplane in the air subjectively, and often it appears that there are nearly as many flying qualities in an aeroplane as there are pilots, who, in other words, frankly disagree about its flying qualities.

In trying to formulate conclusions which shall have a wide application investigators are confronted with a chaos of flying opinion; general conclusions take long to form, and even then have to be accepted with the greatest caution. As long as the pilot has definitely to control his aeroplane by the "feel" of it, as we say, so long will flying remain an art.

I have mentioned the word "feel." Let us get quite clear in our minds about that word. "Feel" is the reaction to the force that the pilot exerts to control the aeroplane, and his perception of the position of the wheel or bar or whatever machinery he uses to exert control. One is not enough without the other. If I turn an aeroplane control wheel round, I perceive how far round I have turned it and the amount of force I am using. Now why do we want to be able to feel the aeroplane, as the rider feels his horse's mouth? A ship is steered by mechanical means and the helmsman follows his compass. Would it not be far simpler if we could rid ourselves of the capricious human element and reduce the control of an aeroplane to a series of mechanical operations? Anyone can see that it would, but let us face the facts and see what is involved.

Anything which is propelled by machinery or natural forces and directed by a human being has some form of controls. The sheets of a sailing ship, the steering wheel of a car, are controls. The tiny skiff is directly controlled by the

man and he has the direct feel of the rudder. As the boat becomes larger the rudder becomes heavier; and if the man is not strong enough to move it he employs a form of gearing. The larger the ship the more sluggish are its movements and the less is the strength of a man relative to the power required for control. Finally, the big ship is controlled by a steam gear and the "feel" is gone. Thus we see that relative size is one of the factors which will measure the desirability of "feel."

But an aeroplane moves in three dimensions while a surface ship only moves in two; the control of an aeroplane is then far more complicated than that of a ship, far more, I should like to say, than in the ratio of three to two. Not only this, but an aeroplane is supported by an element many hundred times less dense than a ship; and although as aeroplanes become larger with increasing moments of inertia the tendency is for "feel" to be less and less desired, I consider that no aeroplane of the sizes reached to-day, or likely to be reached in the near future, will justify the exclusion of "feel." The time factor is too important, the supporting element too tenuous, too elastic, the movements of the aeroplane too sensitive, the need for delicate exactitude so vital, that confidence of the pilot in his controls lies above all in "feel."

I have said that "feel" is the perception of the force on the control and the position of the control mechanism; but that is not all. The pilot moves the control mechanism and judges with his eyes the resulting motion of the aeroplane. That is another factor in control. Since movement involves acceleration, the pilot will feel it in his body. Normally he feels his own weight, or gravity acting on him; if he imparts to the aeroplane an acceleration, the force on him, or apparent gravity, may be increased or decreased. Everyone knows what it is like when a lift starts to move up or down. In some manœuvres this force may rise to as much as four times gravity. This is another way that the pilot has of judging the effect of his control movements. The last way is by means of his instruments; these usually consist of an airspeed indicator, an aneroid barometer, a compass, a lateral bubble, and only too seldom an instrument called a turn indicator. In short, the pilot flies by "feel," by optical perception of the aeroplane motion, by the apparent force of gravity, and by his instruments. By none of these in themselves can he safely control the aeroplane under all conditions, and by the loss of any, at least in the present stage of development, his control is impaired.

Let us subtract them one by one and look at the result. I have already indicated the loss to the pilot if his "feel" is subtracted. Now preclude him from observing the motion of the aeroplane with his eyes, in other words put him into a thick cloud. Many of you, if you have not flown, have walked up a mountain side through a cloud, and you know what it is like. Without his eyes the "feel" and apparent gravity are of comparatively little use to the pilot and he relies on instruments. Nowadays I am glad to say that they have been so developed that a pilot can maintain the aeroplane on a reasonably good course and in steady flight, provided he is at a safe height above the ground; but he dare not approach the ground nor try to land on it, mainly because his aneroid barometer only shows him a relative height and not the actual height above the ground he may be over at the moment; and because, if it did, it would not be sensitive enough to make safe landing possible even if the pilot had any means of telling if the ground were suitable for landing. Therefore the loss of the pilot's optical sense of the movements of the aeroplane is not satisfactory under all conditions.

Now imagine, if it were possible, that the pilot could rid himself (which of course in practice he could not) of the changes in apparent gravity. I do not think he would lose very much, though to a skilled pilot the changes in these forces are in some ways helpful. Lastly, make him fly without instruments. The early pilots did this by force of necessity, but no one would think of doing so now, and it would be impossible to fly through clouds.

Take a submarine. This is a craft which moves in three dimensions, just as an aeroplane does. The submarine commander has to make rapid decisions when his craft is near the bottom in order to avoid hitting it hard. I believe that in these sort of circumstances there is always a desire for a direct form of control; the engine-room telegraph begins to feel too cumbrous for the man's nerves keyed up and waiting for the response. Now an aeroplane, because it goes much faster, may be approaching the ground ten times as fast as the submarine approaches the bottom. Do you wonder that the pilot wants to have the "feel" of the controls and his fingers on the pulse of the engine?

A pilot must not be a slave to any one of these methods of perceiving the motions of his aeroplane consequent on his control; he is most likely to worship his instruments, and he may suffer a bitter disillusionment one day if they show incorrect readings. His senses, his reason and his instinct must balance up his fleeting perceptions and assist him to form his judgment of the right things to do. It has been noticed that in some manœuvres the pilot may be subject to large and extraordinary forces, forces which a person scarcely ever feels in ordinary life, and these must have their inevitable physiological reaction on him. They may give him some indication of what the aeroplane is doing, but they may also make it difficult for him to exert himself physically and mentally.

If his hand feels three times as heavy as in normal life it is more difficult to move the controls sensitively; and if his head feels crushed into his body his reasoning powers are not enlivened. Luckily the large forces on the pilot are not usually long sustained in practical flying, so that the physiological effect is not serious; if they are they do actually occasion some considerable risk, as in a long spin.

The controls of an aeroplane are necessary to take it off the ground, to climb it, to fly it level, to manœuvre it and to land it. Suppose that the instant the pilot ceases to control the aeroplane it is upset by a gust and falls over sideways, or plunges downwards, or sits on its tail, as we call it; you can imagine what a mental strain it is flying such an aeroplane, hour after hour, through wind gusts and foul weather. If physical effort is involved in the control, as it is in the larger aeroplanes, it is a physical as well as mental strain.

Thus at some time or another a widespread desire began to make itself felt for what is termed stability; that an aeroplane should look after itself to some extent; that it should not behave like a floating barrel and tip over if you sat on it, but rather as a pendulum behaves and return to a stable condition if left alone by the pilot. An aeroplane would be completely stable if it would right itself from any position it might have got into owing to a gust or even deliberate action of the pilot. It would always require some space to right itself, and some time; the quicker it would right itself the more stable it would be said to be. The process of righting itself nearly always involves the loss of some height, so it is safer to fly well clear of the ground, for if you upset near the ground you may strike it without a chance to recover. A pilot gets to know particular types of aeroplane and their characteristics; with some he will carry out daring manœuvres comparatively close to the ground, because he knows that they do not take much space to recover in case of an upset; with others he is extremely cautious and allows himself much more space or height. Many valuable lives have been lost through the ignorance or carelessness or deliberate risk taken in this way.

You will now see what I have been telling you about has been concerned with control and stability, the two most important things to a pilot from the point of view of safety. The pilot thinks more about these subjects than anything else, as they are ever present problems to him. I shall have more to say about them later, but before proceeding further I want to go back to the beginning. If a man is going to learn to fly he ought to know why his aeroplane rises into the air and what keeps it there. That sounds simple enough, but most accidents arise from

a disobedience, whether conscious or unconscious, of fundamental laws. Most of you are probably familiar with the broad outlines of aerodynamics, some of you have doubtless gone more deeply into the subject. Will you pardon me if I just look at it from the point of view of the pilot who has to fly and dwell on a few truths which essentially concern him in the art of flying his aeroplane.

I will assume we are going to fly a standard tractor biplane, which has a fuselage or body with an engine and propeller in the nose, two sets of main planes one above the other and a tail plane behind. It has, of course, an undercarriage with a pair of wheels on which it runs along the ground before rising and after landing.

Now it is obvious that an aeroplane will not stay up in the air unless there is some force keeping it up and counteracting its weight, which is all the time dragging it down. This force is, as you know, the result of the passage through the air of the aeroplane's inclined wing surfaces, which give a downward motion to the air over which they have passed. The quicker the wings move through the air the greater is their lift, and conversely the slower they move the smaller is their lift. The lifting force depends on the angle of the wings to the relative wind, that is, their angle of incidence; on their size and on their velocity relative to the air; if the angle of incidence, as it is called, is kept the same, the lifting force is proportional to the square of the speed. If you know what the lift of the wing is at one particular speed you are enabled to say what its lift will be at other speeds, and you can plot a series of curves showing lift against speed at various angles of incidence. I spoke a moment ago of relative wind. I do not mean the wind we experience when we walk down the road. Suppose you are sitting out on the wing of an aeroplane, you will obviously feel a wind whistling past you even though in the ordinary sense there is no wind blowing. This current of air that you feel we call the relative wind, and its speed is of course equal and opposite to that of the aeroplane through the air. But if there is an actual wind blowing in the opposite direction to that of your flight your speed over the ground will be your speed through the air minus the speed of the wind. If your airspeed is 100 m.p.h. and the speed of the wind against you is 30 m.p.h., your speed over the ground will be 70 m.p.h. Conversely, if the wind is with you, to get your speed over the ground, you have to add the wind speed to your airspeed.

Now before an aeroplane can rise into the air the lift on the wings must be greater than the weight of the aeroplane or otherwise it would not start to rise. Pilots do not always realise this, especially when learning to fly, and try to use their controls to get off too soon, with unpleasant results. So you have got to run along the ground first, and opening out your engine to full throttle, gradually run faster until a certain speed is reached, usually about 45 m.p.h., when the lift becomes equal to the weight. After this speed has been passed the lift on the wings can overcome the weight of the aeroplane and lift it into the air. It is obvious that the weight is fixed, so the lift you want is fixed; and in consequence of this, for steady flight there is only one speed possible for a given angle of incidence. When you are getting off the ground a time comes when you realise by the feel of the aeroplane that it is entirely air-borne.

If when you get off you fly steadily in one direction you may climb to a certain height, fly level at that height, and then glide down again. In each case your lift will just balance your weight, and it will be the thrust or pull of the propeller which will settle whether you go up, level, or down. Now you have got to employ a certain amount of power in overcoming the air resistance, and the faster you go the greater is the power required in doing this. You know the great amount of resistance that the air offers to any large surface when you try to push it quickly through the air. Go outside and try and run with an open umbrella in each hand; then imagine what it would be like to drag forty umbrellas

along, and think what it would be like to drag them ten times as fast, when you would have to pull a hundred times as hard. The force required to drag an aeroplane through the air would be as great as this, were it not that the wings are so shaped as to get rid of as much resistance as possible. Even then engines of three and four hundred h.p. are in common use to-day.

In addition to the resistance of the wings there is the resistance of the body, the wires, the struts, and the undercarriage. You know how every effort is made to streamline these to reduce resistance. The opening in the body where the pilot sits makes a tremendous amount of resistance alone; even the wheels have covers; and all projections, where they cannot be eliminated, are carefully faired off.

But what is the effect of the air resistance which inevitably remains after the maximum possible reduction? As was shown before, the resistance requires a certain amount of engine power to overcome it, and the greater the speed of the aeroplane the more it requires. The only limit to the speed is when all the power the engine will give is used up in overcoming the resistance. We have now arrived at a definite speed range for the aeroplane in level flight. It can go no slower than the lower limit, neither can it go faster than the upper. A frequent speed range of to-day is from 45 m.p.h. to 120 m.p.h., which is very large compared with older aeroplanes that frequently had a range of from 40 m.p.h. to 70 m.p.h.

It has now been demonstrated how fast the aeroplane can fly and why it can fly no faster. What happens if it is flown rather slower than its top speed? It would then have a certain power reserve, as the resistance is not so great as at top speed. What can be done with this reserve? It can be used for climbing. The greatest rate at which you can climb is settled by the size of this power reserve. I will show you a curve soon which will demonstrate this reserve pictorially. If you increase the power, you have a greater reserve for climbing or you can use the extra power to increase the top speed.

Again, suppose the engine to be shut off. If the aeroplane does not maintain a certain minimum of speed, it will fall down rapidly; so the only way of maintaining this speed is by going down hill or gliding, that is, by using gravity as your motor. A glider, of course, uses this means of propulsion.

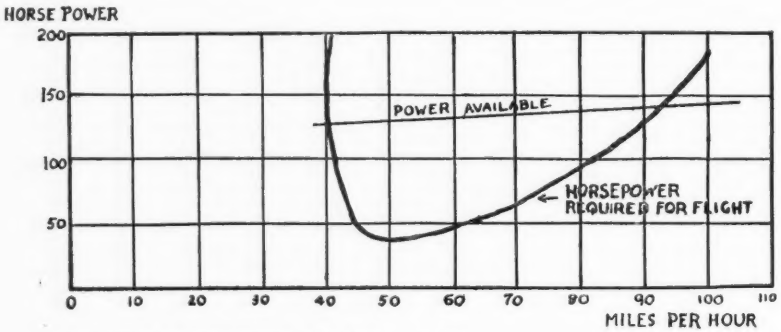
Let me now take a homely comparison, namely, the bicycle, which serves rather well to illustrate what flying is like; you will see how you have to obey similar laws in both cases.

The starting, climbing, flying level and gliding of an aeroplane are very similar to what happens on a bicycle. Before you can start on a bicycle you must get up a little speed or you will fall over. When you have started you must imagine yourself to be the engine. You are on a level road and you pedal harder and harder and gain speed until a limit is reached where you can go no faster. Then you are exerting all your power in overcoming the resistance of the wheels on the ground and the air resistance.

But now if you go rather slower than that, you will have a certain amount of reserve power which you can use when you come to a hill, and the steepest hill you can climb depends on the amount of reserve power you have, in other words, how strong you are. When you are climbing as steep a hill as you can you may be only going 6 or 7 m.p.h., while on the level you go 16 or 17 m.p.h.; just the same happens in the aeroplane. When it is climbing steeply it goes forwards at about 60 m.p.h. while on the level it might be able to do 120 m.p.h.

Then on a bicycle, if you stop pedalling, which corresponds to shutting off your engine in flight, unless you can maintain your speed you will fall off, and you can only maintain your speed by free-wheeling down hill, which corresponds to gliding. On both bicycle and aeroplane, the steeper you come down the quicker you go.

We have now seen how an aeroplane maintains its flight and does not fall suddenly to the ground when the engine is shut off, but glides down steadily; it certainly does not behave in the way described by the American gentleman who assured an old lady that there were hundreds of gallant aviators dying of starvation up in the sky, whose engines had stopped by mistake and who consequently could not get down.



HORSEPOWER AND SPEED FOR LEVEL FLIGHT.

This figure refers to an aeroplane weighing approximately 1,500lbs., and shows a curve representing the h.p. that an engine suitable for driving it would give near the ground at various speeds. You see that the h.p. available goes up a little as the speed rises owing to the increased engine revolutions and the increased efficiency of the propeller. The other curve shows the h.p. required to fly the aeroplane level near the ground. You will see that this particular aeroplane cannot fly at any speed below 40 m.p.h. where the curves intersect, and cannot fly faster than 93 m.p.h. where they again intersect. The curves for any other aeroplane would be similar in shape to these ones.

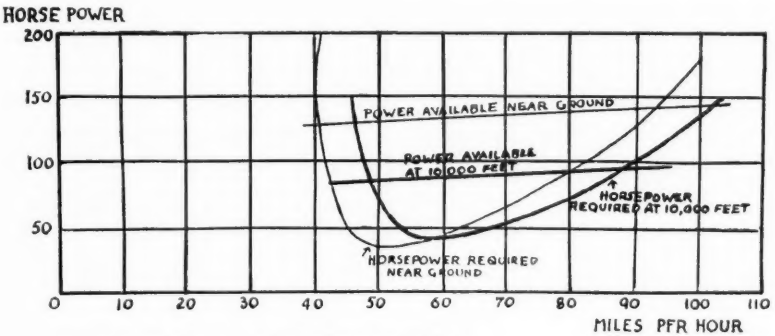
I am not prepared to go into how these curves are arrived at. For students of aerodynamics there is no better book than Professor Bairstow's.

The curves, however, show pictorially what I have been talking about, and you can see quite plainly the reserve of power at any speed which you can call on simply by opening the throttle wide and which can be used for climbing. You can also see the large range of speed from zero at which flight is not possible. It is through trying to fly near the ground in the latter area that 80 per cent. of aeroplane accidents happen. It is interesting to notice that in this aeroplane the minimum power requirement occurs when you fly near 50 m.p.h. You need actually more power at a lower speed, such as 45 m.p.h.; that is why you climb best at a speed rather above your lowest speed, because you have the largest reserve of power. Every pilot is interested in knowing the best forward speed to climb his aeroplane at, in order to rise quickest. However, in practice you have a certain latitude in the speed you can choose; and if it is a little higher than the theoretically best speed, the rate of climb is not reduced very much.

We are now dealing with points which affect the economics of flight; this subject does not so vitally concern the war pilot, because the conditions of his flight are usually dictated by other and more urgent reasons, such as freedom from annoyance by anti-aircraft fire, or the necessity for shooting at troops on the ground; but it does come in where flying has to be made to pay, and the question of the cost is ever present. From looking at these curves you will see that it is obviously the most economical to fly near the speed at which you need minimum h.p. and use least petrol. In this case it is in the neighbourhood of

55 m.p.h. But if you are flying from London to Paris you may encounter adverse winds of 20 m.p.h. and upwards. This would reduce your ground speed to 35 m.p.h. and you would take an absurdly long time to get there. Therefore it would not pay to fly so slowly as this. These are some of the things you have to think of in weighing up at what speed it is most economical from all points of view to fly.

Now I will show you another figure, which is simply the last one with a second set of curves introduced.



EFFECT OF HEIGHT ON THE SPEED OF FLIGHT.

The curves show the change in conditions when you have climbed to a height of 10,000 feet. At this height the density of the air is about three-quarters of the density near the ground, and as you go higher still, the density decreases more and more. You will notice that the curve of h.p. available at 10,000 feet has come down; in other words, as you climb higher the h.p. that the engine can give at full throttle falls off. It is easy to see why this is so. The power developed by an engine at each explosion is roughly proportional to the weight of explosive mixture. To obtain good results this must always be kept in a certain ratio of petrol to air, I believe about 1 : 15, therefore the power depends on the weight of air sucked in at each suction stroke. As you climb higher and the air becomes less dense, less weight of air can be sucked in and therefore less petrol, so the power falls off. At the present time experiments are being made with superchargers, which deliver air to the intake under pressure and put in more weight of air at each stroke, thus mitigating to some extent the effect of the reduced density. In America an extraordinarily successful climb was made by Major Schroeder to over 30,000 feet, using a supercharger.

But you see that not only has the power available curve come down, but the curve of h.p. required to fly at 10,000 feet has been displaced to the right. Again I do not propose to enter into details of arriving at the curve, but in a general way, without much thought, you can see why this is so. You will notice that the new point of intersection showing the lowest speed is nearly 50 m.p.h. instead of just over 40 m.p.h. This is because the air is rarer and cannot support the weight of the aeroplane at such a low speed. In spite of this the top speed is actually reduced and the speed range narrowed down. There must come a time as you go higher and higher and the engine power falls off, when the curve of h.p. required will only just touch the curve of h.p. available. We call this point the ceiling of the aeroplane; after that it has insufficient power to climb any more at whatever speed it is flown; in fact the speed range has gradually been narrowed down till it does not exist, and you have one speed of flight lift which will just maintain you at your ceiling.

The curve of h.p. required to fly at 10,000 feet is plotted on the basis of true speed. As a matter of fact the pilot's airspeed indicator would not show this speed at 10,000 feet.

As the aeroplane travels through the air, the air blows into the pressure head, which has an open end, and the instrument simply shows a difference between this pressure and the static pressure, that is, the pressure that an ordinary barometer would record by means of a pressure gauge. The pressure head is connected to one side, and the static head, which has a closed end with little holes drilled round the side, to the other. As you climb higher the air, as we saw, becomes less dense and blows in less hard, so that the instrument reads low. At 60 m.p.h. indicated near ground level the reading falls off roughly at the rate of one mile an hour for every thousand feet climbed.

You would not try to fly the aeroplane to its ceiling unless you were out for an altitude record, as it feels too uncomfortable on the controls. When you carry out performance climbs you usually break off when the aeroplane climbs no faster than 100 feet per minute, and this is usually termed its " service ceiling," in other words, its " ceiling " for all practical purposes.

Now observe another point. It pays to fly high because, neglecting the lower speeds, you actually use less power at a given speed. At 80 m.p.h. near ground level you are using about 95 h.p., whereas if you flew at 10,000 feet you would only use about 70 h.p. to support your given load, which means you would use less petrol. The curves also show that by flying high, apart from the very greatest speeds attainable near the ground, you can either fly at the same speed, that is, do the journey in the same time and use less petrol; or use the same amount of petrol and do the journey faster; or you can do anything between this, saving a little time and a little petrol.

However, in civil aviation aeroplanes will probably not be flown very high, because the passengers will get cold bodies and perhaps cold feet! Notice that when you are using 70 h.p. at 10,000 feet flying at 80 m.p.h., you actually have about 95 h.p. that by opening the throttle wide you could use. This means that you actually throttle your engine down and use it as a lower powered engine. It is one of the most important concerns of every pilot to husband his petrol supply as much as he can.

I will again point to the curve for h.p. required at 10,000 feet, and demonstrate how it can be used in another way. Its use is only approximate, but will serve for the purposes of illustration. It shows you what is the h.p. required to fly the aeroplane near the ground level if you cut down the wing area so as to increase the loading in pounds per square foot. This curve was arrived at on the basis that the air was about three-quarters as dense as that near ground level. It will now show what happens if you were to cut down the wing area of the aeroplane by a quarter, and increase the loading, say, from 6 to 8lbs. a square foot. Economically the same arguments apply as in the case of flying high. As you are supposed to be flying near ground level you must use the h.p. available curve for ground level in conjunction with the curve for increased loading. It pays to fly high or with a heavily loaded aeroplane; the aerodynamic effects are the same. The slowest speed has gone up, but in this case the top speed has also gone up. You use less h.p. to fly at 80 m.p.h. with the heavier loaded aeroplane. As a matter of fact you save a little weight in cutting down the wings, and this weight can be utilised for useful load. As it is obviously economical to fly with heavy loading, where does the limit come? The minimum flying speed goes up, that is, you want more speed before you can rise off the ground, which means you have to take a longer run to get off. Again, the safe speed at which you can land goes up, and consequently you run farther after landing, which makes it increasingly difficult and dangerous. The great motto of civil flying is " Safety first "; this is where safety and economy are opposed.

I have outlined in a general way the pilot's control of his aeroplane; the help it certainly gives him if it is stable; the way in which it rises and maintains itself in the air; its performance under various conditions, and the most economical way in which it may be handled. I now propose to return to the questions of control and stability, which continually crop up and vex us.

Control and stability mutually react on each other; you can see that if the aeroplane possesses aerodynamic properties which enable it to look after itself, they must, if only to a small extent, run counter to the pilot when he wants to change its attitude rapidly; but more of this later.

The first crude aeroplanes came into being in a haphazard way, and most of them possessed in a high degree the negative quality of instability. It was not till long afterwards that the positive quality of stability was evolved. The maintenance of equilibrium in these early aeroplanes depended entirely on the skill of the pilot, and many an enthusiastic pioneer sacrificed his life in this way. Previous mathematical calculation was of little use, and the only way to develop aeroplanes was to take them up and try them. I sometimes try to figure to myself the skill, the pluck, the optimism and the enduring faith in the future of the aeroplane that inspired the early pioneers to carry on in spite of disappointment and often physical injury, and in an atmosphere very often of intolerance and ridicule. They did go on, and their trials and errors have left us the great legacy we have to-day.

The difficulties which enfold the problems of flight are the elementary difficulties of grappling with them, of stating them properly, of giving the scientist a fair road to work on. Would-be investigators floundered in a sea of ignorance; therefore the most fruitful course was to take machines up and try them, to form conceptions of experiment in the climax of an unsuccessful manœuvre, not to rely too much on the testing out of preconceived theories manufactured on the ground. Experiments had to be kept fluid; methods constantly adapted to the revision of fundamental ideas; the whole process constantly stimulated by the ever increasing mass of air experience.

The flying qualities of an aeroplane had first to be experienced as it were by chance; the pilot had to make a steep turn before he knew what he desired of a rudder. The Wright Brothers, I think, really laid the foundation of the modern aeroplane when they enunciated that for three-dimensional control you needed a rudder to steer sideways, elevators to make the aeroplane go up or down, and a form of lateral control by warping the wings which made possible correctly banked turns. Even then the flying qualities of the early Wright aeroplanes must have taxed human skill to the uttermost in satisfying the elementary requirements of flight; but they definitely proved that power-driven flight was a practical possibility, not a wild dream. As I said, the form of their control surfaces, with the exception of warping wings which have been superseded by ailerons, is with us to-day; even the principles underlying the use of ailerons differ in no way from those of warping wings.

The control surfaces vary, of course, in all the different types, but their use is the same. The control stick, which is universally pivoted, is arranged between the pilot's knees, and if he moves it backwards and forwards he raises or depresses the elevators; if he moves it across from side to side he raises one aileron and depresses the other. His feet are placed on the pivoted rudder bar; if he rotates the rudder bar he moves the rudder across. He pushes with the right foot to make the aeroplane turn to the right and with the left foot to make it turn to the left. Similarly, he pushes the control stick forward to depress the nose of the aeroplane and pulls it back to raise the nose; he pushes it to the right to tilt the starboard wing down and to the left to tilt the port wing down. You see the motions of the control mechanism are made so that under normal conditions of flight they correspond with the pilot's observed motion of the aeroplane. There

are certain abnormal conditions of flight in which they do not correspond, and this is where the pilot always goes wrong when he is learning the art of flying, and where he is liable to go wrong even when he is more experienced.

Now besides the aeroplane controls you have the throttle of your engine, the entire business of which is to vary its power. The throttle lever is usually placed on the left side of the pilot's seat, so that he uses it with his left hand while his right hand holds the control stick. What a pilot soon realises when he begins flying is this, that he is entirely at the mercy of his engine if he wants to remain in the air. He may have once or twice tried to remain too long in the air when his engine is failing and come down with a crash. It is really surprising how easy it is to forget this point when you are in the air. You are getting off the ground and have to pass over some obstacle; in the meantime your engine drops power and you still manipulate the aeroplane controls as if it were giving its full power; I have seen dozens of people do it; it nearly always ends in a wreck even if the pilot is lucky enough to escape with a few bruises. We have seen that if the pilot shuts off the engine he must at once commence to glide down or otherwise the speed drops and the lift will not remain equal to the weight; similarly, if the engine shuts itself off owing to a choking carburettor or an obstruction in the petrol system, he must also commence to glide. What is he to do if he is going for a shed and cannot get over it? Well, that is why flying is not always an easy art.

If the engines of a ship stop there is usually some time before any danger need be anticipated. She may drift off her course and finally go ashore; but if the engine of an aeroplane stops something drastic has to be done at once or else considerable danger immediately arises.

Every day the power plant is being made more reliable, but I am sure it will be some considerable time before the standard of reliability of the locomotive or steamship can be attained. The aero engine has to be built so lightly; it is so comparatively frail for the work it has to perform; there is so much vibration of the parts, owing to the lightness of build, that the measure of reliability attained to-day is more the result of sheer ingenuity of design than of solidity and a big margin of strength. The pilot has not got to the stage where he can place implicit faith in his engine, and he must be ready, if only subconsciously, for a possible failure.

Please do not misunderstand the spirit of my remarks on this point. Superficially it appears that the art of flying is beset with lurking dangers. Difficulties only exist to be overcome; but in order that they may be overcome their extent and significance must be unemotionally analysed. Real risk only exists when it cannot be foreseen and eliminated by the pilot. So, if as well as flying skilfully, a pilot wants to play his part in assisting the development of the aeroplane, to fly intelligently; then I am sure that the value to him of a sound grip of engineering principles is incalculable. Truths that he has assimilated during an engineering training, the value of which at one time may have seemed obscure; these will come back to him when he has to test new types of aeroplane with difficult problems of control; will light him on his way; will, as it were, watch over him and guide his judgment. In my next lecture I shall endeavour to show how nearly all the dangers of flying not only can be, but are successfully met and overcome by the pilot who flies with his weather eye cocked open.

(To be concluded.)